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The outdoor substation

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THE OUTDOOR SUBSTATION

BY

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I. DEVELOPMENT OF OUTDOOR SUBSTATIONS.

1. Introduction.

The Outdoor Substation, as an essential part of a high voltage distribution system, has been largely developed during the past 12 years. The New England Power Company was one of the pioneers in this development, their substation at Millbury, Massachusetts, being one of the first outdoor substations in the northern part of the country. During the five years' experience with this company, the writer of this thesis, in his position of Chief Electrical Designer, was partly responsible for the design of all substations constructed by the company during this period, from 1916 to 1921. Some of the more important of these installations were: Woonsocket Substation, 21,000 Kv.-a. capacity; Adams Substation, 12,000 Kv.-a. capacity; Greendale Substation, 12,000 Kv.-a. capacity; Providence Substation, 50,000 Kv.-a. capacity; Vernon Switching Station, 36,000 Kv.-a. capacity. These installations will be described later.

This thesis is an account of the development of the Outdoor Substation, factors to be considered in the selection and arrangement of equipment, methods of operation, and examples of some of the writer's designs.

of outdoor substations. Because of the great breadth of this subject, its divisions must be dealt with briefly.

2. Factors Causing Development of Outdoor Substations.

The first cause of development of the outdoor substation was principally an economic one in connection with service to the small consumer directly from the high tension transmission line. In order to provide such service before the use of the outdoor substation, either an indoor substation or long secondary lines were necessary. The cost of either method was not justified by the probable revenue received for the service. However, by means of the outdoor substation, isolated customers requiring only a few hundred Kv.-a. could be profitably served directly from high tension transmission lines.

The problem in furnishing service to the small consumer is to keep to a minimum the investment in substation equipment. This results in a minimum in fixed charges, interest, depreciation, taxes, insurance, etc., which are of importance in the cost of such service. The cost of general equipment for substations such as transformers, circuit breakers, lightning arresters, etc., varies little for different types or makes. Consequently, the cost of the substation cannot be much reduced by selection of equipment. The problem of minimum cost is focused upon the elimination of all unnecessary equipment and the utmost simplification of the arrangement of the equipment. The simplicity of design and construction results not only in a small investment but also a minimum of operating troubles. In order to supply electric power service at a low cost, the fixed charges on the cost of the equipment, the maintenance cost on the apparatus, and the cost of attendance must be a minimum. The development of the outdoor substation has helped to bring these results.

Although the greatest incentive in the development of the outdoor substation was the need of providing service at minimum cost to the small consumer, the first application, excepting small distributing transformers, was in a large capacity substation, of the Niagara, Lockport, and Ontario Power Company at Lockport, N. Y., in July, 1906. In this substation the transformers, oil switches, and control equipment were located indoors, while outdoors were placed the buses, the selective disconnectors, and the lightning arrestors. Thus only a small amount of equipment was located outdoors.

By 1909 transformers had been built for outdoor service. The maximum capacity then possible, about 500 Kv.-a. for self-cooled transformers, was large in comparison to capacities of distributing transformers but small in comparison to present day practice. During the next three years, to 1912, more than 100 transformers with total capacity of more than 60,000 Kv.-a. were installed in outdoor substations. These transformers had capacities up to 3,333 Kv.-a., and voltages up to 110,000. This period marks the beginning of real activity in the development of the outdoor substation.

By 1915 there were few large transmission companies which did not have at least some high tension outdoor substations; the total capacity of the transformers in operation being more than 300,000 Kv.-a.

A detailed account of the development since 1915 would be of great length. A brief account of the development of outdoor equipment during this period will be given later. Capacities installed, voltages, and wider use of outdoor equipment have all been greatly increased. The first outdoor substation constructed for 220,000 volts was the Vaca Substation of the Pacific Gas and Electric Company. This substation was first operated in 1922. The transformer capacity per three-phase bank at this substation is 50,000 Kv.-a. The total capacity of the transformers installed at present,

(1923) for 220,000 volt operation is over 700,000 Kv.-a. A summation of the present total capacity for all voltages would result in a very large figure. At present, over 80 % of high voltage transformers are being designed for outdoor service.

In recent years, the greatest incentive for the development of outdoor substations has been economy in interconnection of power systems, and in distribution of large quantities of power at high voltage. The outdoor substation is a necessary part of systems which distribute power at high voltage; it has been an important factor in making such systems possible.

3. Development of Outdoor Equipment.

When the advantages of the outdoor substation became apparent, manufacturers developed the outdoor weather-proof transformer which was followed by outdoor switching and protective equipment. The outdoor transformer eliminated the necessity of bringing the conductor through two roofs, namely, the roof of the transformer and the roof of the building. Oil circuit breakers were developed similar to those used for indoor service except that they had weatherproof construction and bushings. For less expensive forms of switching equipment, various types of air-break switches were developed. The protective equipment included first the aluminum cell and the horn gap arresters, and later the oxide film and the compression chamber arresters.

The use of such equipment soon developed from an experiment to standard engineering practice. Wider applications of this type of equipment were then found. Substations of large capacity were developed, particularly step-down transformer substations used in connection with high voltage transmission and distribution systems. A later development was the use of the outdoor substation at the sending as well as at the receiving end of the high tension transmission line. Thus, at the power station it is now standard practice to locate indoors: generators, excitation system, low tension buses, low tension oil circuit breakers, and switch-board; and to locate outdoors: transformers, high tension buses, high tension oil circuit breakers, and lightning arresters. The outdoor equipment at the power station thus forms an outdoor step-up transformer substation.

4. Future Development of the Outdoor Substation.

The outdoor construction has thus far been largely confined to step-down transformer substations, and, to a lesser extent, to step-up transformer substations and switching stations. A further development seems entirely possible in the use of this method of construction for substations for interurban railway service. In addition to the equipment used thus far in outdoor substations, these railway substations would contain motor-generators or synchronous converters. With enclosed protection which is now given railway motors, these forms of rotating and commutating apparatus may be installed outdoors. Further development of equipment would make this possible.

There seems to be no reason why all the main machinery of a power station, particularly a hydro-electric station, may not be located outdoors. The modern umbrella-type generators furnish their own protection against the weather. The problem of cooling generators out of doors would be simplified. The moisture within the machine would probably be the same, located indoors or outdoors, for two reasons, namely: the heat produced in the generator would free it from moisture; in the indoor type of machine now used, large quantities of outdoor air are passed through the machine in the process of cooling.

It would be best to locate the metering, controlling, and regulating equipment within a small building. Commutating machinery as exciters could be arranged for outdoor service as are street railway motors. Other items of power station equipment as transformers, oil circuit breakers, lightning arresters, buses, induction regulators are now available for outdoor service having been developed for use in outdoor substations.

The attempt to produce a power station having extreme flexibility has frequently resulted in an intricate and costly station. Frequently this flexibility in connections is not justified, because of possible trouble due to intricate arrangements, and the fixed or overhead charges due to high cost. The object to be sought in station design should be to build a station of maximum simplicity with due regard for necessary operating requirements. This simplicity is one of the most important features of the outdoor construction.

5. The Outdoor Substation in Foreign Countries.

a. Conditions Favorable to Development of Outdoor Substation.

The development of outdoor substations has been most marked in countries having electrical power systems with concentrated sources of energy at considerable distance from the point of application. As the appreciation of communities for the benefits of electric service has increased, a greater demand has developed for service from the nearby transmission lines connecting the energy sources and the points of application.

b. Outdoor Substations in England.

Before the demand for outdoor equipment was developed in England, British manufacturers began the development and production of outdoor equipment in order to compete with Continental and American producers in foreign trade. The application of outdoor equipment in England was retarded because the conditions favorable to the development of outdoor substations, as noted in paragraph (a) above, were lacking; and because the districts where power service was available were thickly populated and were, therefore, unfavorable to the development of the outdoor substation. When the electric service companies sought customers in the more remote districts, conditions favorable for the outdoor substation developed and its use increased. However, this station is still less common in England than in America or in other parts of Europe. Its use may increase further as the proposed super-power systems of England are developed.

c. Outdoor Substations in Japan.

Some of the most noticeable differences between American and Japanese practice in outdoor substation design, are the more extensive use in Japan of pin type insulators and of air-break switches. Much of the apparatus is similar to that used in this country; this may be partially due to the fact that the General Electric Company has an interest in some of the electric power supply companies in Japan and furnishes much of their apparatus. The insulators for outdoor substations in many installations, however, have been furnished by the Nippon Porcelain Company; it is likely that insulator development by this company has been more in the line of pin type than suspension type insulators. However, no definite statement can be made regarding the universality in Japan of certain methods which differ from American methods as data on Japanese practice written in English is not sufficient to indicate universal practice.

d. Outdoor Substations in Europe.

The presence of many Thury, high voltage, direct current, transmission systems in Europe has been unfavorable to the development of the outdoor substation. Commutating apparatus, which is an essential part of the substation equipment of the Thury system, has not yet been developed for outdoor service. Consequently, substations in the Thury systems must be of the indoor type.

In regions where high voltage, alternating current transmission systems are being developed, as in France and in Switzerland, the outdoor substation is becoming more common. The general features of design of these substations are similar to features in American practice. In much of the reconstruction work in France, and in the proposed super-power system, the outdoor substation has an important place.

II. FIELD OF APPLICATION OF OUTDOOR SUBSTATIONS.

1. The Small Consumer.

One of the most important fields of application of the outdoor substation is in serving the small consumer directly from high voltage lines. In agricultural districts, farms, dairies, and small towns are thus able to have central station service at a price generally more attractive than that for service from an isolated plant. In industrial districts, factories, without being located in a city, can obtain central station service at a reasonable price. The outdoor substation will thus have an important influence in the decentralization of our industries which will result in better living conditions for the workers. Other examples of this type of an application are mines, and quarries.

2. The Switching Station.

A secondary field of application is in the form of a switching station in connection with high voltage transmission systems. This may be located at: (1) an important operating point of a system; (2) at a junction point of several lines; (3)at a place for interchange of power between two or more power systems; (4) at a point where a tap is made from a transmission line to a substation which is located at some distance from the transmission line; (5) at a point for sectionalizing and reconnecting or interconnecting a double circuit transmission line.

3. The Large Capacity Substation.

A third field of application is in large capacity installations in connection with a high voltage transmission system. In addition to supplying a large load, this type may also have the functions of a switching station. This type of substation is generally a combination of the outdoor and indoor types, a building being desirable for part of the equipment, for the operators, and for a place where repairs may be made.

4. The Electric Railway Substation.

A fourth field of application is in electric railway systems. At present a large part of the energy used on electric railways is generated as alternating current, transmitted to substations, where it is converted into direct current and distributed to feeders. For city systems the outdoor substation would not be suitable, but for interurban lines and electrified trunk lines it has a wide field of application.

5. The Super-power System substation.

A fifth field of application is in connection with national or regional super power systems. Much preliminary work has been done on such a system for the northern Atlantic States; while an actual installation has been made in California.

When the problem of transmitting large blocks of power over distances exceeding 200 miles was presented, it became evident that this was outside the economic field of existing transmission voltages. Consequently, the highest voltage formerly used in practice was increased to 220,000 which was the first substantial increase in ten years in the maximum voltage of power transmission.

After an extensive study and survey of the power resources of the country, Mr. Frank G. Baum developed a plan in which the country would be divided into twelve regional power districts all of which would be interconnected with 220,000 volt constant voltage transmission lines. It would be almost necessary to make the outdoor substation part of such a plan. It is likely that the entire 220,000-volt system would be of the outdoor construction, both at the sending and the receiving ends.

Doubtless a super power system will eventually extend throughout the country. The trunk or primary transmission circuits will transmit energy, probably at 220,000 volts, from hydro-electric stations located at points determined by water falls, and from thermo-electric stations, located near coal mines or at points to which coal is readily and cheaply transported. This energy will be transmitted to outdoor transformer substations located at or near load centers or at a junction point of a lower tension distribution system. At these substations the voltage will be stepped down to 110,000, 66,000, or 33,000 volts, etc., depending upon the extent of the load area or upon the voltage of the connecting system. Nearby generating stations will also supply energy to this secondary transmission system which will serve directly the large consumer and in some cases the small or medium sized consumer by means of outdoor substations. This system will also supply energy to distributing substations which in turn will distribute energy at a lower voltage, 13,200, 4,400, 2,300 etc., depending upon the area served by each substation. Interconnections with other large systems will be made on the high voltage primary transmission system in order to gain advantages of economical interchange of energy at high voltage over long distances.

The outdoor substation will thus have an important part in the development of a national power system.

III. ADVANTAGES OF THE OUTDOOR SUBSTATION.

1. Low First Cost.

A definite comparison of first costs of indoor and outdoor substations is difficult due to the fact that costs are dependent upon local conditions, and upon the function and the design of the station. The difference in the costs of the indoor and outdoor substations increases as the voltage increases.

2. Simplicity in Construction and Operation.

One of the principal results of the outdoor type of construction is simplicity. Because of the absence of elaborate and complicated arrangements of equipment, highly skilled men are not required to keep the apparatus in working condition. This simplicity also results in fewer mistakes in operation.

3. Ease of Enlargement or Alteration.

The outdoor substation can be laid out, especially if the unit-type system is followed, so that it can be extended indefinitely without increase in the initial expense greater than that required for the initial installation. For an indoor type of substation, if provision is made for future extension, generally the building must be made larger than that required for the initial installation. This results in an increased investment charge. The investment charge for the outdoor type of station is a minimum for the initial installation; and for each extension as the load increases, the investment charge is proportional only to the extension at a given time.

4. Less Communication of Trouble.

Because of the greater spacing between conductors and equipment, less damage is done to nearby apparatus when one part fails. In the indoor type of station, a failure of one piece of apparatus frequently causes failure in the adjacent piece, and thus the process continues. An explosion is less confined in the outdoor type station and its effects are less disastrous.

5. Less Fire Hazard.

In the outdoor type of station a fire in a piece of apparatus, or in a part of the station, is more easily confined to the place where it started.

6. Ease of Making Repairs.

Equipment can be easily, quickly, and comparatively cheaply repaired and put back into service in the minimum time. Thus, the time when it is not producing revenue as well as the time when the service may be interrupted or impaired is a minimum.

7. Less Time Required for Providing Service.

Frequently, when a customer decides that he requires central station service, he wants it as soon as possible. Also there may be cases of emergency where a private plant has been destroyed and where the customer is without power service. The time required to design and to install a substation of the outdoor type is much less than that required for the indoor type.

8. Increased Safety to Operators.

Because of the greater spacing, and of less confinement in case of an explosion of an oil switch or lightning arrester, the danger to the operators who may be nearby is less in the outdoor station than in the indoor station.

9. Overload Possibilities in Winter.

In most power systems, the peak load comes during the winter. The maximum allowable load on a piece of apparatus depends upon its temperature. If the cooling effect can be increased, due to a cooler surrounding atmosphere, the allowable load can be increased. Consequently, if the equipment is outdoors, the power output during cold weather may be increased.

10. Increased Salvage Value.

If service supplied by an outdoor substation is to be discontinued, or if the station is to be moved, there is considerable salvage value. The steel fremework can be taken down, by removing bolts, and reassembled in a new location with but little loss. If an indoor station is moved, most of the building is a loss. This advantage is of importance in supplying service to lumber camps, quarries, mines, etc., where work is of a temporary or changing nature.

11. Readily Adaptable to Local Conditions.

Topographical conditions, as for example a hillside, may be such that an indoor type of station is economically impossible. The outdoor type, however, can frequently be adapted to such conditions by terracing.

12. Transparency.

Much of the equipment of an indoor type station is enclosed in masonry compartments. In contrast with this, a large part of an outdoor station is in view from any point of observation. This results in making possible a quick inspection of the station in order to locate a piece of apparatus that has failed or is about to fail. Also failures of insulators in the bus structures may be readily noticed, particularly at night.

IV. DISADVANTAGES OF THE OUTDOOR SUBSTATION.

1. Greater Difficulty of Making Repairs in Bad Weather.

Very wet or cold weather will hinder work on repairs unless provision is made for removing apparatus to a repair shop which is frequently provided at large outdoor substations.

2. Danger to Public.

It is easier to keep the public out of a building than out of a large open area. In order to reduce the danger to the public, it is necessary to surround the outdoor substation by a suitable fence which cannot easily be passed over.

3. Restrictions on Location.

Because of greater spacing, a larger area is required for the outdoor substation. Consequently, it can not be located where land is unreasonably expensive. This generally prevents the selection of a location in a thickly settled region.

4. Less Attractive Appearance.

The question of appearance is generally closely related with the question of cost. In the outdoor substation, costs are reduced to a minimum. Consequently, expenditures merely for sake of appearances are not justified, and seldom made.

5. Reduction in Capacity in Summer.

Since the output of apparatus is limited by the temperature, the additional heat developed in equipment in the sun may cause reduction in allowable output. In order to reduce this effect, the equipment should be painted a light color. Also the rate at which cooling water is pumped through transformers may need to be increased. In extreme cases it may be necessary to provide shade for some parts of the equipment.

V. OUTDOOR SUBSTATION EQUIPMENT.

1. Selection of Equipment.

The substation designer does not design the equipment forming the component parts of the station. He is concerned with the selection and arrangement of equipment which will result in simplicity, safety, minimum of apparatus, minimum of steel, minimum of space, flexibility and interchangeability of circuits, and possibility of extension without disturbance of the former installation. Consequently, a complete discussion of the design of the various parts of substation equipment will not be given. Some brief descriptions of some of the most important parts of the equipment will be given, and some features discussed which are of importance in the selection of the equipment of outdoor substations.

2. Transformers.

a. Single Phase vs. Three-Phase Units.

Transformers for outdoor substations may be either single phase or three phase. Since one unit of the single phase type is generally sufficient for reserve capacity when this type of transformer is used, the investment required for reserve capacity is less than that required when three phase transformers are used. Two single phase transformers may be used to supply three phase service at 57 per cent of full capacity in case of failure of one transformer. In instances where the capacity is to be increased in the future, two units may be installed at first and the third one added when the increased capacity is needed. Three phase transformers require less space, and they are cheaper than a three phase bank of single phase transformers. In some cases, the connections to a three phase transformer are more easily arranged than are the connections to a single phase transformer bank, and fewer bushings are needed except when the single phase units are of the single bushing type. The use of three phase transformers is becoming more common for moderately high voltages but for high voltages, single phase units are more generally used.

b. Transformer Tanks.

Transformers in sizes below 25 kv-a. have smooth cast iron tanks. For sizes from about 25 kv-a. to 750 kv-a. the tanks are made of corrugated sheet steel in order to reduce the weight and increase the radiating surface. For sizes from about 750 Kv-a. to 2500 kv-a. the tank is provided with radiators or with steel tubes welded in the ends of the boiler plate tank. This self-cooled type of transformer with the increased radiating surface, eliminates the difficulties of the water cooling outfit. Generally, for sizes above 1500 kv-a., the tanks are of steel boiler plate and a water cooling coil is provided.

c. Transformer Terminals.

The terminals for low voltage transformers are brought out through porcelain bushings underneath the rim around the top of the tank. This type of transformer, however, is seldom used in outdoor substations. The terminals for high voltage transformers are brought out through the cover of the transformer by petticoated porcelain bushings. For very high voltages, these bushings are of the oil filled type. The terminals should be adapted for connection to pipe or rod.

d. Transformer Mounting Wheels.

Wheels should be provided for transformers rated at 200 kv-a. or more. For small sizes of transformers, wheels without flanges may be used and the transformers mounted on concrete slabs. For large sizes, flanged wheels should be used, arranged for mounting on standard gage rails which should be located on concrete foundations. The most common arrangement of the wheels is such that the center line through the wheels is perpendicular to the center line through the two high tension bushings. It should be possible, however, to mount the wheels in a position 90 degrees from said position, in case it should be so desired.

e. Transformer Taps.

Transformers are generally provided with taps in order to be able to maintain a given low tension voltage with the high tension voltage differing from normal. For example, both windings may have four 2½ per cent taps in order to maintain constant low tension voltage with a 10 percent change in high tension voltage above or below normal. Some transformers are provided with a tap changing switch so that the taps can be changed without opening the transformer. This switch should not be operated with any load on the transformer.

f. Specified Temperature Rise.

The temperature rise of transformers depends upon the load, and upon the temperature and rate of flow of the cooling water. A temperature rise, as 40 degrees Centigrade, will be specified at rated load with a given rate flow of cooling water at a given temperature. For a continuous overload, as 25 percent, a temperature rise of 55 degrees Centigrade is frequently specified with a greater rate of flow of cooling water.

g. Specified Efficiencies.

Efficiencies at various loads and power

factors are generally specified. For example, at 100 per cent power factor the efficiencies for a certain transformer for $1\frac{1}{2}$, 1, $\frac{3}{4}$, $\frac{1}{2}$, and $\frac{1}{4}$ times full load are respectively: 98.5, 98.6, 98.5, 98.2 and 97.0 per cent; while at 80 per cent power factor they are: 98.1, 98.2, 98.1, 97.5, 96.2 per cent.

h. Specified Voltage Regulation.

Voltage regulation is generally specified, as for example, for a certain transformer, at 100 per cent power factor, regulation is 0.9 per cent; while at 80 per cent power factor, regulation is 4.4 percent.

i. Acceptance Tests.

Some of the tests applied to the transformer before acceptance are the high potential tests consisting of double normal high tension voltage applied between high tension winding and transformer core; and double normal low tension voltage applied between low tension winding and transformer core. Double normal high tension voltage is also applied to the high tension winding. These tests last one minute.

j. Specified Dimensions and Weights.

Some of the dimensions and weights are usually specified, a knowledge of which is necessary in the design of the substation. For example, the height to the top of the high tension bushing, the height to the top of the cover, and the diameter are usually specified in the contract. Also the weight of the transformer complete with oil, the weight of the oil, and the weight of the core are usually given. The weight of the core must be known when the transformer lifting tower is designed.

k. Gages, Temperature Indicators, Valves, Outlets.

The location of gages, thermometers and valves on the transformers is generally not definitely fixed, but permits variation according to local conditions and arrangements. The location in individual cases should be fixed so that operators on reading gages and thermometers need not come dangerously near the high tension leads. Electrical temperature indicators remove the need of reading the temperature at the top of transformers. The indicator can be located at any desired point — the switchboard being the most common location. Care must be taken in determining the correct location of water and oil outlets and valves; these must be located so that they can be readily disconnected and so that they will not interfere with the removal of the transformer to the repair house.

l. Means of Preventing Oil from Freezing.

If transformers are to be out of service during cold weather with the temperature near zero Fahrenheit, provision must be made for preventing freezing of the oil. This may be done by (1.) energizing either coil of the transformer, the resulting magnetizing current being sufficient to prevent freezing of the oil; (2.) Electric heating units may be located within or under the transformer; (3.) if the transformer is water cooled, warm water from other transformers that are in operation may be pumped through the cooling coil of the disconnected transformer; (4.) if a heating unit is employed it may also be used to keep the air, which is above the oil, at a temperature above that of the outside air; consequently, when air is drawn into the transformer during breathing periods the moisture in the air is held in suspension — is not condensed and mixed with the oil.

m. Oil Conservator Type of Transformer.

In order to prevent air, laden with moisture, from being drawn into the transformer tank when the transformer oil contracts, and in order to remove the air in contact with the oil in the transformer tank, the "oil conservator" type of transformer has been developed. This type of transformer has an oil tank for oil expansion , connected with and located above the main tank which is made oil tight. The air is thus eliminated from the main tank. The auxiliary oil tank or conservator is connected with the outside air through a calcium chloride breather which removes most of the moisture from the air entering the auxiliary tank. The moisture, which is condensed in the conservator, is removed by a pet cock attached to a sump. The original insulating value of the oil in the main tank is thus preserved.

The heating of the oil in a transformer tank may form a combustible gas if air is present. This gas may be ignited by a static discharge or by other arcing and result in a violent explosion. The formation of this gas is prevented in the conservator type of transformer since the oil, which is in contact with the air, is not heated. Furthermore, in the conservator tank there is no opportunity of ignition since it contains no electrical conductors.

If the transformer oil is heated in contact with air a heavy sludge is formed which clogs the oil ducts and forms a heat insulating coat on the coils and core in the transformer. The removal of the air from the main transformer tank prevents this decomposition of the oil and the resulting interference with the process of cooling.

Some materials used for insulation in a transformer deteriorate much more rapidly when the hot oil in which they are immersed is exposed to the air. The removal of the air due to the conservator reduces this deterioration.

An objection to the oil conservator type of transformer is the difficulty of maintaining an oil tight joint between the main tank and its cover. If a transformer will not be subjected to over-loads, with the resulting excessive heating of the oil, the plain type of transformer may be preferable.

n. Transformer Connections.

The high tension side of transformers in substations is preferably arranged for Y connection as it permits the system to be operated with the neutral grounded, with all the advantages that accompany such connection. Unless a grounded neutral system on the low tension side is desired this side is preferably arranged for delta connection. This Y - delta connection for transformers is becoming more and more general practice. An examination of methods of transformer connections in 75 of the leading power systems shows that 35 companies use this connection.

In some cases, as for example, when a substation receives power from a high voltage system, as at 220,000 volts, and distributes power to another system at a lower voltage, as at 110,000 volts, a grounded neutral may be desirable on both the high and low tension sides. In such cases, the transformer should be provided with a tertiary winding connected in delta. This winding is necessary in order to take care of the triple frequency component of the magnetizing current. This tertiary winding may be used to supply the power load required for operation of the station, or it may be used for the operation of synchronous condensers.

3. Oil Circuit Breakers.

a. Advantages of the Oil Circuit Breaker.

One of the most important parts of the equipment of the outdoor substation is the oil circuit breaker. This type of a circuit interrupting device is generally used in outdoor substations, except in installations where the cost must be a minimum, and where the amount of energy interrupted is very small. One of the most important advantages of the oil circuit breaker is that, when interrupting the flow of energy, it causes but little disturbance in the circuit. The oil circuit breaker can be controlled from a distant point, and can be made to operate automatically with its operation accurately timed with respect to the occurence of a certain condition in the circuit as, for example, excess current, reversed power, etc.

b. Oil Circuit Breaker with Automatic Reclosing Equipment.

In addition to opening automatically, the oil circuit breaker can be arranged to close automatically. For example, when an oil circuit breaker on a feeder circuit opens automatically, on overload, auxiliary equipment can be arranged so that it will be reclosed after an interval of from 5 to 30 seconds, depending upon the time setting. If the overload remains when the breaker is closed, it opens again and closes again after a similar interval. If the overload still remains on the circuit, the breaker opens again and is locked open until it is manually reclosed and reset. Other equipment can be arranged which will prevent additional operation of the breaker whenever the load on the circuit is beyond the safe interrupting capacity of the breaker. After this equipment has operated, the breaker must be inspected, and reset by hand before it can be closed again.

c. General Features of Oil Circuit Breakers.

The tanks of oil circuit breakers should be removable without disturbing the contacts or the mechanism. This permits easy inspection of the contacts and allows adjustments and repairs when necessary. One tank, containing all phases, is satisfactory on low voltage, but since outdoor substations are generally operated on high voltage the type of breaker used for this service should have separate tanks in order to isolate the phases. The tank must be designed so as to withstand whatever pressure may be developed in the tank when the breaker opens on short-circuit. The tanks of very large breakers are not removable. The bushing, contacts, and cross-head of large breakers should be arranged so that they may be readily removed from the top of the tank and a man-hole should be provided in the tank in order to permit adjustment of contacts.

The contacts should operate under a comparatively deep head of oil which absorbs the explosive force caused by the interruption of a short circuit and also prevents excessive development of gases. The contacts should be of a high pressure type with a wiping or self-cleaning action. The main contacts should be protected by renewable arcing contacts which break the circuit after the main contacts have parted. The acceleration and the movement of the contacts should be rapid in order to minimize the duration of the arc, and to prevent the tank pressure from rising to an excessive value.

An expansion chamber should be provided with baffled vents for the escape of gases. The space above the oil in the tanks also acts as an expansion chamber. The vents should be adequate to discharge the gases but should not permit oil to be discharged from the breaker when opening on overload within the capacity of the breaker.

Breakers for outdoor service are mounted on a pipe or structural steel framework whenever the size is such that the tank of oil can be lowered for inspection of contacts without disturbing the line wires. For moderate or large sizes, a tank lowering device is part of the equipment. Very large breakers are arranged for floor or platform mounting with a removable cover which gives access to contacts, and with removable bushings and contacts, as previously stated.

d. Methods of Operating Oil Circuit Breakers.

Small circuit breakers may be manually operated by means of a lever mounted on a panel or on the breaker. Since small oil circuit breakers are seldom used in outdoor substations, manual operation of breakers is uncommon for this equipment.

Because of the large force required for operating large breakers, and because of the desirable high speed of operation, the most common method for substation circuit breaker equipment is electrical operation. The standard method of operating outdoor circuit breakers is by means of solenoids operated on direct current which is supplied from a storage battery. The operation of the solenoid may be controlled at a distant point by a control switch in connection with a control relay when the current required by the solenoid is larger than that which the control switch can handle.

In some special cases where direct current is not available for operation, the equipment may be arranged for alternating current operation. This can be done by applying motor-operating mechanisms to standard solenoid operated circuit breakers. The motor operated mechanism gives higher speed operation, since the time required for building up the magnetic field of a solenoid is eliminated. It is also possible to arrange equipment for use of alternating current in solenoid operated circuit breakers.

e. Methods of Tripping Oil Circuit Breakers.

In the non-automatic circuit breaker, the electrical control circuit, connecting the tripping coil with the operating bus, is governed by manual operation of the control switch. In the automatic breaker, this tripping circuit may be completed automatically by relays which are governed by conditions existing in the power circuit. These relays may be arranged to operate on a number of conditions such as, over-current, over-voltage, under-voltage, reversed power, balanced power, etc. If it is desired that the oil circuit breaker will trip automatically for more than one condition, generally more than one set of relays is required.

f. Interrupting Capacity, and Duty of Oil Circuit Breakers.

Two terms in common use in the selection of circuit breakers are interrupting capacity, and duty. The former means the highest value of root-mean-square current at normal voltage and frequency which the circuit breaker can interrupt under a given duty. This duty is an assumed condition that the breaker will interrupt its rated r.m.s. interrupting capacity current two times at a two-minute interval, and then be in condition to be closed and carry its rated normal current until it can be inspected and adjusted.

The interrupting capacity in r.m.s. amperes at normal rated voltage and at various lower voltages is given by manufacturers for their various types of oil circuit breakers. If the automatic circuit breaker reclosing device, previously mentioned, is used on the oil circuit breaker, consideration must be taken of the manufacturer's interrupting rating as based upon the two-minute interval. In such a service, the circuit breaker will generally be called upon to operate at an interval of from 5 to 30 seconds. Consequently, for a given service, a breaker with a larger interrupting capacity must be used than that which would be necessary if the interval of operation corresponded with that of the assumed duty upon which the interrupting capacity rating is based.

g. Factors Determining Selection of Circuit Breakers.

The following factors should be considered in the selection of an oil circuit breaker for a given circuit:

(1.) The highest normal voltage of the circuit, or the highest rated voltage of transformer secondaries feeding the system to which the circuit is connected.

(2). The normal r.m.s. current of the circuit.

(3). Length of time of short circuit before breaker opens, and the maximum magnitude of the current which the breaker must withstand under short circuit conditions.

(4). The r.m.s. current on short circuit at instant of parting of circuit breaker contacts.

(5). Altitude at which breaker will be operated.

(6). Temperature at which breaker will be operated.

Items (1) and (2) are easily determined and need no further discussion. Items (3) and (4) are factors which are very difficult to determine. The length of time of short circuit before breaker opens depends upon the time setting of the relays governing the operation of the breaker. The total r.m.s. current on short circuit is the square root of the sum of the squares of the different components of the current which form the total short circuit current. The circuit breaker must be able to withstand the magnetic forces and the heating effect of the maximum value of this total short circuit current before the circuit is broken. Manufacturers give "short-time" ratings of circuit breakers in r.m.s. amperes for one second, and for five seconds. The short-time, or one second, rating of an oil circuit breaker must be at least equal to the maximum or initial value of the short circuit current in the circuit.

The r.m.s. current on short circuit at instant of parting of circuit breaker contacts determines the necessary interrupting capacity of the breaker. It is beyond the scope of this thesis to explain in detail the method of determining the short circuit current at any point on a power system where an oil circuit breaker is to be located. Some of the factors upon which this short circuit current depends are:

(1). The total kv-a. capacity, the reactance, and the transient characteristics of all synchronous machines connected to the system at a point of which the short circuit occurs.

(2). The characteristics such as resistance, reactance, and capacitance, and the arrangement of all circuits and all reactors over which energy can be transmitted to the point of short circuit.

(3). The kv-a. capacity, resistance, reactance, and capacitance of all transformers through which energy can be transmitted to point of short circuit.

(4). The contact resistance at the point of short circuit.

(5). The type of short circuit — single phase or three — phase.

(6). The kv-a. capacity and the power factor of the load being carried at the time of short circuit.

(7). The point of the voltage wave at which the short circuit started.

(8). The effect of automatic voltage regulators in maintaining the voltage.

This short circuit current may be determined by several methods, namely:

(1). By calculation.

(2). By actual test (if the system is complete.)

(3). By short circuit testing tables which represent in miniature form the complete power system.

The last method is becoming more and more popular. An approximate determination by calculation may be readily made by ignoring many of the above factors upon which the short circuit current depends. In this method, resistance and capacitance are neglected, only reactance being considered; and use is made of a group of time-current decrement curves which have been determined experimentally on similar systems.

The altitude at which the breaker will be operated (item (5) of factors determining selection of circuit breakers) has an influence upon the terminal bushing. At high altitude the dielectric strength of air is reduced. Consequently a circuit breaker for a given voltage at high altitude must have bushings with larger dimensions than that for low altitude.

The temperature at which the breaker will be operated (item (6)) has an influence on the type of oil used in circuit breakers. When the breaker is to be installed in a location where freezing temperature may exist, the oil used is a special, treated, mineral, low-temperature oil which has a freezing point at -30 degrees C., in one type of oil. This oil has an insulating value such as to withstand 40,000 volts when tested between 1/2 inch disks two-tenths of an inch apart. It has a flash point of 155 degrees C., and a burning point of 180 degrees C.

h. Outdoor Protection for Oil Circuit Breakers.

The low voltage circuit breaker (2300 to about 6600 volts), when installed in an outdoor substation, is generally of the indoor type enclosed in a weatherproof switch house, which also contains low tension buses, instrument transformers, meters, relays, etc.

The circuit conductors enter and leave the switch house through standard roof bushings in roof of switch house. The circuit breaker is the ordinary indoor type with either separate tanks for each phase, or all phases in one tank.

For voltages of about 11000, or higher, the oil circuit breaker for outdoor substation service is equipped with standard interchangeable bushings mounted on steel collars, with gaskets making a waterproof connection to the circuit breaker housing. For high voltage these bushings are of the oil filled type and are interchangeable with similar bushings for transformers, and lightning arresters. The solenoid and the connecting mechanism operating the moveable crosshead in the circuit breaker are enclosed in a weatherproof housing.

4. Lightning Arresters.

a. Purpose and Use of Lightning Arresters.

The purpose of lightning arresters is to protect the equipment of the substation, particularly the transformers, from induced charges and other disturbances on the transmission lines. Protection against a direct stroke of lightning is not intended. When this occurs on the line, the voltage is generally in excess of the flash-over voltage of the insulators; consequently, the charges pass to the ground around the insulators. If the charge does not have potential high enough to jump the insulators, it travels along the line in both directions until it is dissipated in heat losses in the conductor, in corona, or through lightning arresters. At a bend in the line, the discharge meets additional impedance; here the impulse is practically reflected, the voltage builds up and flash-over may result. The frequency of this charge passing along the line is determined by the natural frequency of the line. A lightning arrester assists in maintaining normal voltage on lines, discharges excess potential to earth and limits the resulting flow of current by automatically extinguishing the arc as the voltage falls to normal. Each incoming or outgoing line may be equipped with lightning arresters; or the arresters may be connected to the high tension buses which may result in a reduction of the number of arresters required. Each outgoing feeder circuit is usually equipped with an individual arrester. Arresters may be of either the three or the four tank type, the latter being the most common and required for the ungrounded neutral system.

b. Compression Chamber Multigap Arrester.

The compression chamber multigap arrester is used in small customers'substations where the cost of the oxide film or aluminum cell types is not warranted. This arrester consists of a series of multigaps and a resistor in a porcelain tube. The brass alloy electrodes with porcelain separators, forming the gaps, make a small closed chamber in the tube. When a discharge through the arrester occurs, gases are formed by the arcs across the gaps and, since the gases are held within the chambers, they become compressed. This assists in extinguishing the arc. This arrester is available for voltages up to about 15000. Since outdoor substations are generally for higher voltages, this arrester has a limited field of application.

c. Graded Shunt Resistance Multigap Arrester.

The graded shunt resistance multigap arrester is the more usual type used where the investment and the service do not justify the installation of the aluminum cell or oxide film types. This arrester consists of a number of brass alloy cylinders, with a small air gap of 1/16 inch, or less, between them, connected between the line and ground. Part of the gaps are shunted by resistances which give a low break-down voltage, and limit to a safe value the normal frequency generator current which follows the lightning discharge.

The potential gradient is highest across the first gap at the line side of the arrester. With a certain voltage this gap breaks down; the voltage rises across the second gap until it is likewise broken down. This process continues until the discharge current flows to ground either across all the gaps or through a combination of gaps and resistances depending upon the frequency of the discharge current. This is followed by the generator current through one of the resistance paths.

The arcs between the brass alloy cylinders produce vaporized zinc which permits the flow of current only in one direction. When the generator current passes through its zero value and attempts to reverse, it is cut off by the rectifying action of the vapor.

This arrester is not suitable for high voltages because of the large number of gaps which would be required to prevent the arcing over of line voltage. It is available for voltages up to about 15000 for outdoor service.

d. Aluminum Cell Arrester.

The aluminum cell arrester until recently has been the standard type for the protection of equipment for which the highest degree of protection is justified. This type of arrester requires daily charging; consequently it cannot be installed in an unattended station. The arrester should be installed so that its connections to the incoming lines will be as direct as possible.

The aluminum cell arrester was adapted for outdoor service by the development of an oil and an electrolyte with low freezing points. In order to avoid extreme heat and the possibility of the development of gas in the tanks, the arrester should be shielded from the direct rays of the sun when the heat is excessive. If the heat is not excessive — which is true in most parts of this country — the arrester will be sufficiently protected by white or light colored paint.

This arrester is equipped with standard interchangeable bushings described elsewhere. Consequently, the altitude of point of application must be considered in the selection of the arrester.

An element of the aluminum cell arrester is a cell consisting of two aluminum electrodes in an electrolyte. On the surface of the electrodes, by electrolytic action, a thin film of aluminum hydroxide, having a high resistance, is formed. This film prevents the flow of current, except that of small value, until the applied voltage reaches from 300 to 350 volts per cell, approximately, which is called the critical voltage. When this critical voltage is reached, the current is limited only by the internal resistance of the cell which is very low. The excess voltage above the critical voltage determines the value of the current which equals this excess voltage divided by the resistance of the cell.

If the applied voltage is near the critical voltage, a small current passes which is partly a leakage current through the resistance and partly a condensive current. If a lower voltage is applied, the thickness of the film and its resistance is reduced so that a temporary critical voltage is formed near the applied voltage. If the leakage current were allowed to flow continuously, it would cause serious heating and formation of gas which would cause a serious explosion. In order to prevent the continuous flow of this leakage current, a spark gap is put in series with the arrester, the gap being adjusted so that current flows when the voltage exceeds the normal line voltage.

The cells in the arrester are formed by inverted aluminum cones supported by treated wooden rods and separated by fiber washers. The number of these cells depends upon the line voltage. In practice, the number is such that the voltage per cell is between 250 and 300. The space between the cones is partially filled with the electrolyte — a solution of ammonium-tetra-borate—for installations where the temperature does not go below 5 degrees C. For installations where the temperature is below 5 degrees C., the electrolyte is a mixture of ammonium-tetra-borate and ammonium-tartarate. The tartarate dissolves the hydroxide film faster than the borate and should not be used unless it is needed. The stack of cones is placed in a steel tank which supports the terminal bushing at the top. The tank, and the remaining space between the cones, are filled with oil for insulation and cooling and for the prevention of the evaporation of the electrolyte.

For voltages above 73,000, the tank is of elliptical shape and contains two stacks of cones in order to keep to a reasonable height. The stacks of cones are connected in series and are insulated from the tank which is grounded. In the lower voltage type, the tanks are mounted on insulators and the cones are connected to the tank.

Since the electrolyte dissolves the film on the aluminum electrodes, it is necessary to charge the cells daily. The extent of this dissolution depends upon the temperature of the electrolyte. Consequently, with extremely high operating temperatures more frequent charging may be necessary. The charging operation consists of closing the gaps through a charging resistance which dampens the oscillations of the charging current resulting from the arc, and also limits the initial flow of the charging current.

e. Lightning Arrester Gaps.

The time interval required to rupture all types of insulations varies with the nature of the insulation, the shape and spacing of the electrodes, and the frequency and magnitude of the applied voltage. This time interval, called the dielectric spark lag, is a minimum for sphere gaps. Consequently, this type of gap is used in aluminum cell and oxide film arresters in order to give protection against sudden impulses or waves with steep wave front. The aluminum cell arrester has a main gap and an auxiliary gap in parallel, the latter being in series with the charging resistance. This auxiliary gap has the lower setting so that disturbances are usually discharged through it unless they are too heavy, then they break down the main gap which does not have the limiting resistance. The arc then rises to the auxiliary gap where it is broken in series with the resistance which dampens the oscillations.

f. Oxide Film Arrester.

The oxide film arrester furnishes protection similar to that furnished by the aluminum cell arrester and because of several points of advantage it is gradually superseding the aluminum cell arrester.

An element of the oxide film arrester is a disk-shaped cell about 7½ inches in diameter and 5/8 inch thick consisting of two circular brass plates crimped firmly to the edges of an annular piece of porcelain; the space between the plates is filled with lead peroxide which has very low resistance; the inside surface of the plates is covered with a varnish film which has very high resistance.

When a discharge passes the spark gap, and a voltage of about 370 volts is impressed on the cell, a small puncture of the varnish film occurs and current flows through the cell to ground thereby relieving the pressure of the discharge. Due to the heat formed by the flow of current through the cell, a chemical change takes place at the point of puncture of the film. The lead peroxide, PbO_2, is changed to red lead, Pb_3O_4, and litharge, PbO, which have very high resistance. This high resistance is thus automatically inserted in the path of the discharge current preventing the subsequent flow of the generator current. The puncture of the varnish film is thus covered by a film of red lead and litharge which has a slightly higher resistance; with continued action the varnish film is replaced by the film of red lead and litharge which is again broken down and replaced by a thicker film; thus the protective value of the arrester decreases with continued use, requiring a higher break down voltage.

The number of cells connected in series depends upon the voltage, about 300 volts per cell being allowed. The cells are clamped together and supported by treated wooden rods. The stacks are then supported on steel racks mounted on insulators. The arrangement of stacks in the four-stack type is similar to that used for aluminum cell arresters. One terminal of each of three stacks is connected through sphere gaps to each of the three phases; the other terminal of each stack is joined

to a common point which is connected to the fourth tank the other terminal of which is connected to the ground; thus, two stacks are connected between any two lines or phases, and two stacks between any line and ground.
For outdoor service, the stacks have a housing of sheet steel louvres. The sphere gaps also are covered so that the gap setting is not affected by rain.

g. Comparison of Oxide Film and Aluminum Cell Arresters.

A comparison of the oxide film type of arrester with the aluminum cell type follows:

(1). First Cost.

The cost of a 66,000 to 73,000-volt, three phase oxide film arrester is about 75 percent of that of a similar aluminum cell type.

(2). Maintenance cost.

The cost of replacing aluminum cells, after being punctured by heavy discharges, is much greater than the cost of replacing cells in the oxide film type of arrester. In the aluminum cell type the oil and electrolyte must be removed and replaced.

(3). Daily Charging.

The oxide film arresters require no daily charging. The result is a saving in energy, and in the labor charge, for attendance.

(4). Discharge Rate.

Since both types of arresters have practically the same discharge rate they give about equally good protection.

(5). Effect of rain on gap setting.

Since the gap can be covered in the oxide film type it will have the same discharge voltage regardless of weather.

(6). Fire hazard.

The absence of oil in the oxide film type reduces the fire hazard.

(7). High frequency surges.

There is less tendency in the oxide film type to cause high frequency surges. In the aluminum cell type the arc is extinguished by means of a horn gap as the arc rises; the oscillations at this arc are likely to cause surges.

(8). Weight.

The shipping weight of oxide film type is less than that of aluminum cell type, resulting in lower freight charges.

h. Recent Developments in protective equipment.

One of the recent developments in the field of high speed gaps, such as are used on lightning arresters, is the impulse gap. The dielectric spark lag of this type of gap differs from that of the sphere gap, which has been previously described. The voltage at which the impulse gap discharges varies inversely as the frequency, consequently the higher the frequency of a dangerous surge, the lower the voltage at which the gap discharges. The discharge voltage of a high frequency surge may be as low as one-half of the discharge voltage at normal frequency. Because of this characteristic, the impulse gap may be set to give that protection against dangerous high frequency surges without permitting too frequent discharges on minor surges at normal frequency.

One of the most recent developments in the field of lightning arresters is the Autovalve Lightning Arrester. This type of arrester has some of the characteristics that the oxide film type has: moderate cost, ease of installation, high degree of protection, simplicity of construction, and no need of daily charging. This is essentially a gap type of arrester with special features to give valve characteristics similar to those of the aluminum cell or oxide film type of arrester. These special features which give this valve action are such as to cause the break down voltage and the voltage across the unit gaps when current is flowing, to be approximately equal.

This unit gap, or element of the arrester, consists of four columns of discs connected in parallel and housed in a single disc shaped porcelain case which is provided with four holes for the discs. Four other holes are provided in the element for bolting together adjacent elements. The two sides of the disc shaped porcelain cases are covered with metal end plates which are spun over the beaded edges of the porcelain case. For moderate voltages, these elements are merely bolted together with a number of elements connected in series depending upon the maximum operating voltage. For high voltages, the columns of elements are assembled in sections of five or six elements and the sections are clamped together with wooden strain insulators, thus preventing tensile stresses in the porcelain.

The type of gap used in the Auto-valve arrester is the sphere gap, both spheres of which are adjustable, thus permitting a close setting of the gap. The gaps are covered with rain sheds in the outdoor type of arrester in order that the setting will be accurate with varying weather conditions.

The Autovalve arrester has the following distinctive features:

(1). The valve action prevents the flow of any power current at normal frequency following a discharge.

(2). The arrester has a low resistance during discharge, so that the voltage drop is low, thus offering a high degree of protection.

(3). There is no chemical action involved in the discharge and no excessive deterioration of the operating parts.

(4). Due to the absence of solid dielectric in the path of the discharge, the active element being a "glow discharge" across an air gap, the operation is very rapid which caudes a discharge to start before the surge reaches a dangerous value.

5. Choke Coils.

a. Function and Location of Choke Coils.

The function of the choke coil is to bring about a reduction in the frequency of any electric oscillation passing thru the coil to the transformer winding. The result of such oscillations in the end turns of the transformer winding would be to cause high potential stresses which are dependent on the frequency of any traveling wave that may penetrate into the winding.

The steep wave front of a disturbance is always partly smoothed out by the choke coil. The location of the choke coil is in series with the line between the connection to the lightning arrester and the apparatus to be protected.

b. Types of Choke Coils.

The choke coil consists of a coil of bare copper wire wound in a cylindrical or hour-glass shape. This coil with the necessary terminals may be mounted on pin type or pillar type insulators, which, in turn, are supported on a steel base, or may be arranged for mounting in a suspended line. This suspended type has a treated wooden rod as a center core which takes the line stress. The rod is fastened into the end clamps which also support the ends of the coil and the terminals. The coil is prevented from sagging by supports connecting the coil with the center rod. The rigid mounting type of the choke coil with pin type insulators is given additional rigidity by an insulator connected to the middle of the coil. The hour glass shape of choke coils gives increased mechanical strength, but only a negligible increase in reactance. The rigidity may be increased by the use of copper clad wire. The coils in this rigid type are sometimes supported, and the turns separated by insulating strips.

If arcing between the turns occurs with extremely heavy disturbances, it is possible that the high frequency disturbances will pass over the strips. The type of coil with only air insulation between turns will immediately re-insulate itself after a discharge passes, while the type with insulating strips will not.

c. Factors Considered in Selection of Choke Coils.

In the selection of the choke coil the following essential requirements should be considered:

(1). The insulation, or air space between the turns, should be sufficient to prevent arcing from turn to turn with maximum voltage which is likely to exist on the line.

(2). The inductance of the coil should be such that the surge or disturbance will be reduced to a value that will not damage the end turns on the transformers

(3). The turns of the coil should have no appreciable capacitance as this would tend to neutralize their inductance.

(4). The mechanical construction should be sufficiently rigid to prevent collapse or distortion of turns during excessive stress caused by short circuits.

(5). The voltage drop across the choke coil at normal voltage and frequency should be small.

(6). The reactance of the choke coil should not be too high. A surge due to switching may originate within the station; if the reactance of the choke coil is excessively high, the surge is prevented from leaving the station and from being dissipated in the line or in the arresters which are connected on the line side of the choke coils.

(7). The characteristics of the choke coil should be specified, as, for example, the number of turns, the diameter of turns, the shape of the conductors, inductance, voltage, current, and frequency.

6. Air-break Switches.

a. Field of Application of Air-break Switches.

An Air-break switch is equipped with arcing horns which cause the arc to be broken in the air when the switch is opened and the circuit is broken. This type of switch is capable of interrupting only a small load, or the charging current of a line, or the magnetizing current of a transformer.

b. Method of Operating.

These switches are mounted on steel bases by means of pin type or pillar type insulators. The switch is generally operated manually by means of operating rods, connected to the three units of a three phase switch.

c. Types of Air-break Switches.

Some of the many types of air-break switches are;

(1). The motion of the blade is obtained by means of an insulator which may be rotated around it's own axis. The blade is raised or lowered in a vertical plane by means of a bell crank connected to the top of the insulator. The pin of the insulator is connected to the operating handle which is rotated and gives rotating motion to the insulator. Because of the torsion on the insulator it's top or pin sometimes breaks.

(2). The motion of the blade is obtained by means of an insulator which rocks around a shaft which is at right angles to the center line of the insulator. Connecting links transmit the motion to the blade. The porcelain insulator in this type is thus subjected to bending which is likely to be more serious than torsion.

d. Contacts in Air-Break Switches.

The Air-break switch may be arranged for one or for two breaks, or arcing horns, per pole. The contacts should be thoroughly protected from ice and sleet so that they will not freeze shut.

e. Use as a By-pass Switch.

In addition to it's usual uses as a disconnecting switch, this air-break switch is also used as a by-pass around oil switches and metering outfits, in order to permit them to be removed from service for inspection and repairs.

7. Disconnecting Switches.

a. Field of Application of disconnecting Switches.

Disconnecting switches, or disconnectors, are used to isolate apparatus during inspection or repair. For this purpose, they are generally located on both sides of oil switches and in the leads to lightning arresters. In connection with an oil switch, they are also used as transfer switches, so that a circuit may be connected to either of two buses. Disconnecting switches are not designed for opening under any load, nor for interrupting the magnetizing current of transformers. The oil circuit breaker should always be opened first in order to prevent the serious arcing and disturbance which results when the attempt is made to break the circuit with a disconnecting switch.

b. Types of Disconnecting Switches.

The disconnecting switch is arranged for rigid or suspension mounting. The rigid type is generally mounted on a steel base with pin type or pillar type insulators, and is arranged for a horizontal position, or for a vertical position with pins and insulators in a 45-degree arrangement. These switches are of single-pole type, and maybe either single-throw or double-throw.

The double-throw type may have two independent blades hinged on the middle point. This type, called a selector switch, is useful in changing a circuit from one bus to the other without opening the circuit. Each type of disconnector should have a guide blade to assist in closing the switch, and a safety catch to prevent the switch from opening, which would be caused by vibration or by repulsion between phases during short circuits.

The suspension type mounting consists of a blade suspended beneath a string of suspension insulators which are connected to the fittings which make up the hinge and jaw of the switch. The live wires are also attached to these fittings by means of a clevis or thimble and a three-bolt clamp. This type of disconnector also should have a guide blade and a safety catch. The jaws of all outdoor disconnecting switches should be designed for operation under conditions of sleet; they are sometimes covered by a specially designed hood for sleet protection.

c. Method of Operation.

Disconnectors of the rigid type are operated ma nually either by a switch hook consisting of a hook on a treated wooden rod, or by a mechanism which is connected to the switch in each phase and opens them all simultaneously. The latter arrangement is safer for the operator and generally permits a more compact arrangement. Suspension disconnectors are operated only by switch hooks.

8. Outdoor Metering Outfits.

a. Field of Application of Outdoor Metering Outfits.

The former practice of metering consisted in installing two current transformers and two outdoor potential transformers, and either a housing for the meters or the meters installed in a nearby building with secondary leads of the transformers extended to the meters. This practice is being superseded in many cases by the use of an outdoor metering outfit which combines the above equipment in a single unit. In large capacity installations where a building is necessary, it is good practice to install the meters indoor, excepting the meters for outgoing feeders which are frequently installed in outdoor metering outfits. In these cases where the meters are installed on a switchboard indoors, the metering outfit is used in place of the separate current and potential transformers because the first cost and the cost of bushing maintenance are thereby lessened.

b. Method of Connection.

The outdoor metering outfit consists of two current and two potential transformers arranged in a single oil tank with a weatherproof compartment on the side for the meters. In this arrangement, only three terminal bushings are required, while, in the former practice, six are necessary. In two of the bushings are the entering and leaving leads of the primary of a current transformer thus forming the one turn or loop. One of the potential transformer leads of each transformer is connected to each of the two incoming leads to the current transformers, while the other leads of the potential transformers are tied together and brought out through the third bushing to the third line of the circuit.

c. Advantages of Metering Outfits.

The use of the metering outfit makes the wiring and connections more simple than that required with separate transformer units. The cost of maintenance of high tension bushings is only about one-half of that for separate units for a three-phase circuit. Extra transformer elements may be kept in stock thus facilitating repairs and reducing time out of service.

9. Bushing Type of Current Transformers.

a. Use and Location.

This type of current transformer is used generally for energizing relay coils and overload trip coils on oil circuit breakers. It is located at the base of the oil circuit breaker bushing and it consists of a secondary winding on a laminated iron core. The primary winding has the equivalent of one turn and is formed by the terminal stud of the oil circuit breaker.

b. Limitations.

Because of the insulation necessary around the stud there is an excessive air gap between the primary and the core. Therefore, for the low values of primary current the ratio is inaccurate. Consequently, these current transformers are not used for metering. They may be used in connection with an ammeter but should not be used with an ammeter and a relay coil or trip coil simultaneously. Circuit opening relays should not be energized from this type of current transformer. In order to increase the range of operation of these transformers, one may be installed in each of the two bushings per phase of circuit breaker and their secondaries connected in series.

10. Terminal Bushings.

a. Types of Terminal Bushings and Their Uses.

The terminal bushing is one of the most important parts of all high voltage equipment. For low and moderate voltages (below 70000) the solid type porcelain bushing is satisfactory. For high voltage (70000 to 220000) the oil filled interchangeable bushing is preferable. This bushing consists of an external shell of porcelain and steel through which a metal conductor, surrounded by insulating barriers, passes from end to end; these barriers are spaced concentrically to form ducts for circulation of the oil. The external shell of porcelain is in two parts which are joined together by a flange clamp and are mounted on the apparatus by a steel sleeve. Due to the interchangeable feature of these bushings they may be used on a power transformer, a current transformer, a lightning arrester or an oil circuit breaker.

b. Flash-over Voltage; and Puncture Voltage.

One of the requirements of a bushing is that it shall have a flash-over voltage lower than it's puncture voltage. When a voltage higher than it's flash-over voltage is applied, a flash-over will then result protecting the bushing against puncture.

c. Time Lag.

Another requirement is that the bushing shall have a large time lag before flashover occurs. Spark gaps, on protective equipment, are generally of the sphere-gap type which has a very small time lag so that although the flash-over voltage of the bushing may be exceeded for a short time, the discharge takes place over the protective gap instead of over the bushing.

d. Corona.

In order to prevent heating of the bushing and the resulting deterioration, it's insulating surfaces should be free from corona at the voltages usually existing on the circuit. Corona may be permitted on metal parts of the bushing but not within the tank on which the bushing is mounted. Corona within the tank is likely to ignite gases formed from the heated oil.

e. Effect of Altitude, and Altitude Rating.

Consideration must be given to the altitude of the place at which the bushing is to be installed. Because of the decrease in insulation strength of the air, with decrease in density at higher altitudes, the flash-over voltage of a given insulator is less at higher altitudes. Since flash-over voltage is affected, the normal operating voltage is similarly affected. For example, a bushing with a normal operating voltage of 150000 volts at sea level will have an operating voltage of only about 110000 volts at 10000 feet elevation. Consequently, bushings are generally given a voltage and altitude rating. The difference between a high and a low altitude bushing for the same operating voltage is shown only in the upper part which is exposed to the air; the lower part, which is immersed in oil, is the same for bushings for equal voltages. The dimensions of the upper part of bushing s for high altitude must be increased because of the decrease in the insulation strength of the air.

VI. GENERAL DESIGN FEATURES OF OUTDOOR SUBSTATIONS.

1. Requirements.

In the design of a substation, consideration must be given to transformation, switching, metering, and protection requirements. While fulfilling these requirements, the designer must also consider the general demands of low first cost, low maintenance cost, safety in operation, accessibility of all apparatus, arrangement to give high salvage value, and layout to permit extensions in the future with least change of existing equipment and least interruption to service.

2. Least Material Necessary for Providing Service.

The aim of the designer should be to determine the least material and simplest arrangement which will accomplish the desired results. Apparatus and material not needed result in an increased investment, the fixed charges on which tend to cause increased rates. They also result in increased maintenance charges. Elaborate switching arrangements, in order to give immunity from interruption of service, are generally not required; interruptions are so infrequent that the cost of providing complicated arrangements of duplicate equipment is not justified. In case the service is so severe that frequent and prolonged inspections and maintenance work are necessary, duplicate buses and switching equipment to prevent interruption of service are justified.

3. Simplicity of Arrangement.

The design and arrangement of the substation should be such that outgoing circuits can be supplied in some way during all ordinary failures of parts of equipment. This does not mean, for example, that the arrangement should permit connection of any transformer to any circuit under some highly improbable circumstances. Reasonable flexibility should be provided, but the switching equipment should be the minimum which is necessary to fulfill service requirements. Thus, the design should be such as to provide the best and most reliable service consistent with the rates which the customer will pay.

4. Flexibility.

After the selection of the main equipment required for a particular service, as transformers, circuit breakers, lightning arresters, the next consideration should be the flexibility in arrangement of connections necessary to insure good service. In the larger stations, particularly of the indoor type, the tendency has been to provide protection against all possible dangers under all conditions, although some conditions may not be probable, in the case considered. The probabilities of danger should be classified into the various degrees of probability and an estimate made of the cost of protection against the danger in each class. A study of the cost necessary to protect against dangers of various degree of probability, will indicate what protective measures are justified.

5. Use of Duplicate Equipment.

Decision regarding the use of duplicate buses and switching equipment should be based upon an economic study of costs and of value in regard to the service to be given. The duplicate equipment should be valued in terms of danger of interruptions to service and the resulting damage. At the time of the initial installation, operating conditions may not fully justify duplicate equipment, but, if future conditions are likely to justify it, provision should be made for its future installation.

Results similar to those obtained by the use of duplicate equipment may be obtained at much less first cost by the use of light transfer buses and by-pass air-break switches; these, however, bring about an increase in operating cost as compared with operating cost with duplicate equipment. Consequently, a study of the probable increase in the operating cost due to lack of duplicate equipment will indicate the amount of duplicate equipment which is justified. In this decision, consideration must also be given to the value of the resulting increased reliability of service with duplicate equipment.

6. Excessive Durability.

The design of a substation with excessive durability should be avoided. Consideration must be given to the probable period of adequacy of the substation. For example, a substation serving a rapidly growing community or industry should not be designed for a service of twenty or thirty years. While the increased demands of such a service for a short period may be met by extensions, after a long period the conditions may be so changed that a completely new design is necessary.

7. Location of Substation.

The location of a substation should be as near as possible to the load center or center of distribution of the area served. Many factors, however, are of greater importance than this load center. Because of its appearance, the outdoor substation would be out of place in many locations; consequently, a suitable location, taking into consideration the surroundings, must be selected. Because of the comparatively large amount of space required, the outdoor substation must be located where the price of land is low. Frequently, local laws have much influence in the selection of the location. Occasionally, the selection of the location must be made according to the land that is available. In addition to these conditions, consideration must be given to the possibilities of the center of distribution changing with the growth of the business.

8. Type of Material for Outdoor Substations.

The type of material used in outdoor substations should be of standard make; this results in least cost, ease of construction, least time of construction, and less highly specialized labor. Also, if the material is available from a standard stock, much less time and expense will be required for replacing damaged equipment. It is an advantage if a type of material is selected which permits easy extension of the substation, and has high salvage value or is easily taken down and reassembled in a new location.

9. Standardization.

In outdoor substation design, there has been a trend in individual companies toward standardization, but there has been no such trend toward universal or even sectional standardization. Particularly in the smaller sizes, each company develops a standard substation of its own. Since the conditions for each installation are different, an arrangement of the equipment for the standard substation should be such as to fit a variety of conditions. Conditions are so widely different for large capacity substations that complete standardization is not possible.

Standard designs may be developed for many parts of the substation, as foundations for various equipment, towers, bus supports, and most of the apparatus, leaving the specific arrangements to be developed according to requirements in individual installations. If a company has several substations, this standardization would result in the reduction of the number of spare parts which must be kept for repairs.

10. Relay Protection in Outdoor Substations.

a. Double Circuit Protection.

Common practice in high tension systems is the use of double high voltage circuits in the form of a closed loop, operating the two circuits in parallel. Since the two circuits are the same, the power transmitted by each of them is the same as long as there are no faults. In order to cut out the section of the circuit in which a fault may occur, balanced power relays are used. These relays are operated in connection with bushing type current transformers which are installed with high tension automatic oil circuit breakers. These transformers, because of their large magnetizing current, are rather inaccurate for low ratios. For the higher ratios, however, at which the transformer is generally used, the transformer is equal to the standard instrument transformer for operation of relays.

b. Single Circuit Protection.

If a single circuit is used feeding in one direction, the outgoing end is protected by overload type relays, while the incoming end of the circuit is protected by reverse power relays in connection with overload time delay relays. If a single circuit is used with the possibility that energy may flow in either direction, protection may be obtained by use of overload type relays on both outgoing and incoming ends of line.

c. Transformer Protection.

For protection against internal troubles in transformers, the oil circuit breakers on the high and low tension sides are equipped with bushing type current transformers, having current ratios inversely proportional to the voltage ratios of the transformer. These current transformers are differentially connected to inverse-time-limit, definite-minimum, induction-type relays. When trouble occurs in the transformer, or in the leads between transformer and its high and low tension oil circuit breaker, the relays will trip both these circuit breakers. Trouble on feeders, causing merely overload, does not operate these relays, so that the transformer circuit breakers are non-automatic with respect to this trouble.

d. Feeder Circuit Protection.

For protection of feeder circuits, automatic oil circuit breakers are used equipped with bushing type current transformers, which are connected to inverse-time-limit, definite-minimum induction relays. In case the reclosing device on a feeder circuit is wanted, in which the air circuit breaker is automatically reclosed and with continued trouble is locked open on the third operation, a notching relay is used in connection with a hesitating control relay. If an oil circuit breaker (instead of air type) is to be similarly controlled,a motor operated timer is used with the automatic reclosing equipment. This timer may control the operation of several breakers, and operates as follows after the breaker has been opened because of a severe overload or short-circuit:

(1). Recloses breaker after a predetermined time interval.

(2). If breaker opens immediately, due to continued trouble, the timer recloses it after a longer time interval.

(3). If breaker opens again immediately, the timer will reclose it after a still longer time interval.

(4). If the breaker opens the fourth time the timer will cause it to be locked open until inspection is made and timer re-set.

The automatic reclosing equipment includes the following relays: hesitating control relay, overload time delay relay, reclosing relay, locking out voltage relay, and locking out current relay.

11. Buses and Bus Supports for Outdoor Substations.

a. Effect of Type of Bus on Steel Supports.

The selection of the type of bus and its supports is largely an economic problem. The steel work for the non-rigid bus must be strong enough to withstand the pull necessary to support the wire with a small sag. This pull for each wire amounts to about 1500 to 2500 pounds depending upon size of wire, length of span, and weight of suspended equipment (as choke coils and disconnecting switches) supported in the span. The load on the steelwork with rigid bus is much less, being only the dead weight of the conductors, connections, and insulators. Consequently, the steelwork may be lighter if rigid buses are used.

b. Number and Spacing of Insulators.

The number of insulators, however, is larger with the rigid bus, giving many more points of possible failure. The number of insulators may be reduced to a minimum by using pipe for the bus which has greater rigidity than a solid conductor for the same cross section of material. The spacing of insulators for a given size and kind of pipe and a given sag may be determined by the usual deflection calculations. Tabulations of the results of these calculations for various sags are given in "Electrical World", volume 70, page 1236. Curves are given showing the deflection of various kinds of pipe for different spacings of insulators, with and without an ice load. The deflections there given are maximum values obtained in calculations for simple spans supported at each end. For a continuous bus, the actual deflection would be less than that indicated by the curves. The spacing of insulators is also influenced by the clearance between conductor and steel which depends upon insulator height, load on conductor, and location of steel with respect to the conductor. A greater spacing of insulators and a greater sag are allowable when the steel members are above the conductor or at right angles with conductor. Most standard insulator pins are too short to provide proper clearance when the conductor is installed above and parallel with the steel support.

c. Effect of Type of Bus on Ease of Extensions.

One of the most important advantages of the rigid type of bus is that its use permits a station to be designed more easily on the unit-type plan, thus allowing extensions to be made with ease. Also, in the initial installation, the steel framework and concrete foundations need not be provided for future requirements. When the non-rigid type of bus is used, consisting of standard conductor and strain insulators, a change of supports is frequently necessary for an extension of transformer or feeder circuits. Another objection to this type of bus is the appearance of connections from the bus to equipment. Especially in a short span, the strain insulators occupy a large part of the span. Connections to equipment, mounted on the same steel support that holds the strain insulators, must be off-set some distance in order to make connection with the bus beyond the strain insulators. This results in an undesirable appearance.

d. Use of Suspension Disconnectors and Choke Coils.

The most important advantages of the non-rigid type bus are that it permits the use of suspension disconnectors and choke coils, and that the points of support of the bus are few in number. Also standard line material can be used for the buses and connections.

e. Present Practice in Buses for Low and High Voltages.

Because of the reasons given in preceding divisions a, b, c and d, it is better practice to use pin-type insulators and rigid bus on low and medium voltage installations, and strain-type insulators and non-rigid bus on high voltage installations.

f. Non-rigid Bus Supports.

For the non-rigid bus, the support is mostly standard line material. It consists of a hook or clevis fastened to the steel support followed by a number of standard disc insulators, the number depending upon the voltage. The insulators are followed either by a special roller clevis, or by a standard clevis and thimble through which the conductor passes and is fastened by a standard three-bolt clamp.

Since about 30% of line voltage is applied to the insulator, next to the conductor, some special arrangements are made at this insulator for very high voltage systems. This percentage in the uneven distribution of voltage over a long string of insulators is practically constant for strings of any number of units above five. Increasing the number of units does not decrease the stress on the insulator next to the line. It is evident then, that, for very high voltages, the voltage across the first insulator is higher than that allowed in good practice. Either of two methods may be used for correcting this uneven distribution of voltage: static shields may be used on standard disc insulators, or the insulator units may be graded by the use of units of large size at end next to line conductor.

g. Rigid Bus Supports.

For the rigid bus, the support should be of the interchangeable unit construction type. In this type, either the petticoat insulator, pin or cap may be replaced or interchanged. If the voltage on the system is raised, only the insulator need be changed, provided the spacing of conductors in the original design is sufficient for the higher voltage. In case it is desired to mount conductors below the insulator, instead of above, part of the cap is attached to the pin, and supports conductor while the cap is then arranged for mounting on the steel support.

For vertical arrangement of conductor it is preferable to mount insulator in a 45-degree position by use of angular pins and caps, although recent tests indicate little reduction in insulation strength with insulator in horizontal position. A vertical position of insulator, for a conductor in a vertical position, may be used with a special attachment for holding the conductor the proper distance from the base of the insulator.

The part of the bus support to be mounted on the steel member should not have more than two mounting bolts. These should be arranged so that the support can be mounted on a single structural angle or other structural form. If the support is to be mounted on pipe framework, the base of the pin should be arranged for U bolts. Cap and pin should be adjustable so that the support can be mounted on a steel member, perpendicular to, or parallel with the conductor, although, if the latter arrangement is used, a special pin may be necessary in order to provide sufficient clearance between conductor and steel.

h. Rigid Bus Supported by Suspension Insulators.

For very large capacities, copper pipe may be used for the bus, in place of stranded cable, and it may be supported by suspension insulators. A catenary type of construction may be used similar to that used in supporting trolleys in electric railways. The supporting cable may be of steel or copper-clad steel. It is attached to the steel structure by means of disc suspension insulators, the number of which depends upon the voltage. The copper pipe is supported from the steel cable at frequent intervals with connectors of varying lengths depending upon distance from steel structure. Turnbuckles should be installed between the insulators supporting the steel cable and the steel structure in order to adjust the tension in the cable. The ends of the copper pipe should also be supported on strain or suspension insulators. Thus, in this arrangement, a high voltage large capacity bus may be supported on four strings of insulators per phase.

i. Rigid Structural Steel Bus.

A recent development in types of buses is the structural steel bus which has the advantage of few insulator supports of the non-rigid or cable bus, and the advantage of light load on the steel structure of the rigid copper pipe bus. For moderate capacities (400 amperes or less), this bus may consist of two 2-1/2 in. x 2-1/2 in. x 1/4 in. galvanized structural steel angles fastened back to back with 1/4 in. spacers. For large capacities, a 1/4 in. copper bar, with width depending upon desired capacity, may be fastened between the backs of the angles.

The copper pipe bus must be supported at intervals of from about 6 to 10 feet. The supports on the steel bus described above may be 22 feet apart resulting in lower cost of insulators and fewer points of possible failure.

If the length of the bus is greater than the length of available angles, they may be fastened together by means of the spacer, and the current carrying capacity of the joint may be increased by the use of standard rail bonds. Connections between buses and equipment can be made by copper pipe which can be connected to the steel bus by means of copper lugs with pipe connection on one end and flat spacer on the other. The steel bus may be supported either by suspension insulators or by pillar insulators.

12. Bus Connections.

a. Types of Connections.

Most connections to equipment should be made with clamp fittings so that a minimum time will be required to disconnect, remove, and replace equipment. Other connections which are not likely to be disconnected may be soldered or welded.

b. Connections to Bushings.

Connections leading to terminal insulators or bushings should be arranged so that there is no appreciable strain on the bushing. Otherwise, the bushing is likely to be damaged.

c. Connections to Lightning Arresters.

Connections should make as direct a path as possible to lightning arresters. Bends or loops in the conductor increase the reactance to the lightning discharges and, consequently, decrease the protection of the arrester. All sharp bends in conductors should be avoided as they tend to cause voltages to be built up at these points when surges occur.

d. Methods of Adjusting for Expansion and Contraction.

Allowance must be made in connections for expansion and contraction. In non-rigid buses or connections, turn-buckles or adjustable eyebolts should be installed, in order that slack may be removed in summer and excessive tension in winter. In rigid connections between equipment and the bus, a right angle bend is sufficient to take care of expansion or contraction. Expansion of a rigid bus is generally taken care of by slipping through clamps which hold bus to insulators.

13. Lighting of Outdoor Substations.

a. Types of Lighting Systems.

Flood lighting may be successfully used in outdoor substations if care is observed in locating units so as to prevent glare in the eyes of operators. In some arrangements of equipment this is difficult; consequently, the more common form of lighting is by incandescent lamps, spaced around the station and located according to the equipment needing light. These lamps are generally mounted with large reflectors and weather-proof sockets on goose-neck supports.

b. Lighting of Equipment.

Disconnectors, particularly the type operated by a switch stick, must be well lighted, also the temperature indicating devices on transformers. Other parts of equipment needing only occasional inspection, as oil switches and lightning arresters, need have only moderate illumination.

It is good practice not to illuminate buses providing they are not in a position where accidental contact is likely. If they are kept dark, defective insulator can be more readily detected.

c. Emergency Lighting.

Special temporary lighting is frequently used in case of emergency repairs at night. Provision for this temporary lighting should be made by installing weather-proof receptacles at convenient points in the substation. If these receptacles have sufficient current carrying capacity, they may also be used for portable oil filters required for filtering oil in oil switches and other equipment.

If the station is of medium or large capacity, so that it will contain a storage battery for operation of the oil switches, an emergency lighting system should be installed. This is accomplished by a low voltage relay which automatically connects an emergency lighting circuit with the storage battery when the voltage at the station falls below a specified value.

In a small station, without a storage battery for operating oil switches, an automobile battery and headlights may be controlled by a similar relay. Thus, in case of power failure, emergency lights are provided that reduce danger to operators and permit faster operation.

VII. SMALL CAPACITY OUTDOOR SUBSTATIONS.

1. Procedure in Design.

In the following discussion of some of the general features of the small capacity and the large capacity outdoor substation, it is not assumed that the designs and arrangements here given are the only possible ones, or that they are the best. Merely standard methods, which have worked out well in practice, will be given.

Outdoor substations of both small and large capacity have many features in common. Consequently, much of the discussion of the former will apply to the latter and vice versa. For any substation there is an indefinite number of possible arrangements; study should be made of many of these arrangements with the aim of selecting the best features of each and consolidating them into a plan that meets the requirements of the service. These service requirements may be indicated by a one-line diagram which is the starting point in the design. A mental picture must then be formed of the possible arrangements which fulfill these requirements. Free-hand sketches clarify ideas; sketches drawn to scale indicate clearances and the necessary modification.

2. Type of Load.

The development of the small capacity outdoor substation has resulted in an increased use of electrical energy in locations distant from central stations. This type of substation allows farms, small communities, industries, mines and quarries, which could not be economically served because of their distance from central stations, to obtain energy from nearby transmission lines. The load thus obtained is generally very desirable for the central station, since it generally tends to increase the load factor and the diversity factor of the system.

3. Minimum Economical Size.

For various transmission line voltages, there is a minimum economical size of outdoor substation that can be connected to the line to give commercial service. This size depends upon many factors, as: cost of producing energy, rates for energy, cost of substation equipment, voltage, etc. These sizes for the usual transmission line voltages found in practice have been given as follows:

Transmission Line Voltage	Approximate Smallest Economical 3-phase kv-a. Rating of Substation
110,000	400
88,000	250
66,000	100
44,000	50
33,000	25
22,000	25
13,200	10
6,600	3
4,600	3
2,300	3

Although transmission lines with voltages of 220,000 are now in operation, it is probable that the substation of minimum economical size will not be used in connection with such lines since they will be used as trunk lines connecting systems, or transmitting large amounts of energy in bulk. Consequently, the highest voltage given in the table is 110,000 which is a moderately high voltage for secondary transmission systems to which small outdoor substations are likely to be connected.

4. Types of Substation Supports.

The usual types of supports are wooden poles, steel poles or steel structures. For a substation of very small capacity on a low voltage not exceeding 13,200, wooden pole supports are generally preferable because of their cheapness. For substations of capacities greater than 100 k v-a, and with voltages higher than 13,200, steel supports are generally preferable.

5. Factors Influencing Choice of Type of Construction.

One of the factors that influence the choice of wood or of steel construction is the probable life of the installation. If a new arrangement must be provided, due to growth of business, before the end of the natural life of wood structures, the use of steel structures is not always justified. At times when the price of steel is very high, or in locations where the price of wood is very low, due to close proximity to a large supply of wood, the use of wood structures may be preferable.

It is good practice to have large spacing when wooden supports are used. Thus, for example, 66,000 volts conductors are spaced 7 feet on a wooden structure and six feet on a steel structure. The object of the increased spacing is to reduce the danger of arcs, with the resulting burned off pins and cross-arms, and the interruptions to service. The particular field of application of the wooden pole substation is in service for small industrial plants, small towns, and for farms.

For capacities over 75 k v-a., or for voltages exceeding 22,000, the steel tower is generally preferable. Since small capacity substations do not have a regular maintenance and repair crew, it is generally wise to have the steel work galvanized rather than painted; the galvanizing should be done after the punching, drilling and fitting are finished, in order to cover all parts; also the steel work should be assembled with sherardized bolts.

6. Types of Secondary Equipment.

The small capacity outdoor substation began as extension of the pole top distribution transformer practice. The transformer was supported on a platform or hung from the pole which supported the transmission line at the top; above the transformer were mounted the switching and protective equipment. For larger capacities, four poles were used supporting a platform on which the transformers were mounted. Because of the difficulty of making repairs on transformers and because of the fire risk, transformers of moderate and large sizes are now mounted on concrete foundations.

If the substation contains constant current transformers for street lighting, or if the low tension voltage is 2300 or less, a building or housing for the equipment will be necessary. If the above conditions need not be met, and if the service does not need intricate switching equipment or the regular work of an attendant, a building is seldom necessary. The cost of electrical equipment in general, arranged for outdoor service, is about 15 to 20% higher than the cost of similar indoor equipment. When the difference in cost between the indoor and outdoor equipment is greater than the cost of a building, an indoor installation should be considered.

For a voltage as low as 2300, the difference in price between outdoor and indoor types of equipment is sometimes sufficient to cover the cost of a building. In small installations this low tension equipment may be enclosed in a building of steel, or wood frame-work, covered with corrugated steel. This building would enclose the low tension oil circuit breakers, instrument transformers, instruments, and relays. Conductors would enter and leave the building through standard wall or roof bushings. Buses may be installed outdoors in order to reduce the size of building necessary. This building, or cabinet, may contain a slate panel for mounting disconnecting switches, automatic oil switch and measuring instruments. The current and potential transformers may be mounted on the side walls; they are not necessary, however, when the voltage does not exceed 440. These compartments, or switch houses, are designed in various standard forms for all the usual types of service, as single phase or three phase light and power, street lighting, etc.; the compartments are available as complete units and are frequently mounted on steel channels in order to permit easy handling. For small capacities a cabinet mounted on the pole or structure is satisfactory.

When the voltage on the low tension side of the substation is greater than 11000, approximately, the equipment would be of the outdoor type rather than being enclosed in switch houses or compartments as for the lower voltages. This type of substation would probably be of sufficient capacity to warrant the installation of a low tension oil circuit breaker. A standard outdoor metering outfit would be used if metering is desired at the substation.

7. General Arrangement of Equipment.

In a satisfactory arrangement of a small capacity outdoor substation, the high tension leads are first connected to an air-break switch, choke coil, expulsion fuses, and then to the transformers. Between the switch and the choke coil the lightning arrester is connected. The low tension leads from the transformers are connected to the terminal bushings of the switch house used on low voltages. In small capacities, the switch house contains disconnecting switches, fuses, and meters, and may be made of wood; in larger capacities, it contains automatic oil circuit breaker, instrument transformers, and meters, and is generally made of steel. When an oil switch is used, the high tension fuse is generally over-fused, so that the oil switch takes care of all ordinary disturbances.

Much of the equipment is available in a "unit-type" form in which, for example, a disconnecting switch, choke coil, and fuse are mounted on a single steel channel. This results in ease of installation and in a minimum number of insulator supports. The material is quickly obtained, comparatively low in cost, and easily adaptable to changing conditions; the equipment is assembled in a large number of arrangements to meet local conditions and complete substations including the steel supports may be purchased as a unit for the usual standard voltages up to 66000; transformers, oil switches, metering equipment, and some forms of lightning arresters, are generally not included; however, as they are usually obtained from other manufacturers. Steel towers are shipped complete with bolts for assembling in the field.

When the load is less than 300 k v-a. the cost of high tension oil switches and aluminum cell, oxide film, or Autovalve, lightning arresters is usually not warranted. In this case, the high tension equipment would include some type of fuse, as, for example, the carbon tetra-chloride fuse, and less expensive forms of lightning arresters, as the multiple gap, the high speed sphere gap, graded resistance, or the compression chamber types. An objection to the use of the fuse is that occasionally only one of the three fuses fails, allowing customers' motors to operate single phase, with the resulting probable damage if the equipment is fully loaded. A method of avoiding this possible trouble is in using an automatic pole top oil switch instead of the costly frame mounted type. With this switch would be used three series overload trip coils with a time limit device which will open the circuit on continued overload but not on momentary overloads. Pull cables may be arranged to close the switch from the ground. This switch is available for voltages up to 15000 but could be developed for higher voltages. When the size of the station does not justify the installation of an oil circuit breaker, consideration should be given to probable growth. If an increase in load sufficient to warrant the expense of an oil switch is likely, provision should be made, when plans are prepared for the original installation, for replacing the air-break switch with an oil switch.

For substations with capacities of about 50 to 300 k v-a., when the expense of an aluminum cell, oxide film, or Autovalve lightning arrester is not justified, a two-pole arrangement is satisfactory. When the transformer capacity is not exceeding three 25 k v-a. units, the transformers may be mounted on the poles or on a platform supported by the poles. For larger capacities, it is preferable to mount the transformers on concrete foundations on the ground, thus reducing the weight on the poles, which weight tends to shorten their lives.

When the capacity is from 300 to 600 k v-a., and the character of the load is such as to require the protection of an aluminum cell, oxide film, or Autovalve, arrester, a four-pole arrangement is preferable. In this case, transformers should be mounted on concrete foundations.

When the capacity is small, or when cost must be a minimum, the lightning arrester on the high tension side is omitted as its cost may not be off-set by the increased insurance against interruption. Protection against lightning is furnished by the overhead ground wire. If the low tension side is connected to an overhead distribution system, an inexpensive type of lightning arrester, as the multiple gap type, would be used.

Buses and connections for a small capacity substation are preferably of copper pipe, if capacity is large enough to warrant it; for very small capacity, solid copper wire is satisfactory in sizes larger than No. 4 B. & S. gage.

If the substation is to be used for lighting service, automatic induction regulators on the low tension feeders would be desirable. For small capacity substations, these regulators would be of the outdoor type. For large capacity substations, if the low tension equipment is mounted in a building, or in compartments, the regulator may be similarly mounted and may be of the indoor type.

8. Measuring Instruments in Small Substations.

If the substation serves a single customer, the energy may be metered at the station; if, however, several customers are served, the metering equipment must of course be located so that individual demands will be recorded. In this case, totalizing meters may be desirable in the substation as a check on the customers' meters or as an indication of losses in distribution. If this is not considered essential, potential transformers will not be needed at the substation unless there is a source of power on the customers' side of substation and a possible need for synchronizing. Current transformers, however, will be needed for tripping oil circuit breakers on over-load or short circuit on feeders.

Since rate schedules are frequently based upon a maximum demand charge as well as an energy consumption charge, both watt-hour meters and maximum demand measuring apparatus are needed. A recording or graphic wattmeter affords a good means of measuring maximum demand. The energy consumption is measured by the integrating watt-hour meter. Since rate schedules also frequently contain a power factor clause, a reactive volt-ampere indicator for registering the power factor is needed. In some cases in recent practice, rates for electric service are based upon kilovolt-amperes instead of energy consumption of kilowatts; for this purpose kilovolt-ampere meters are available.

VIII. LARGE CAPACITY OUTDOOR SUBSTATION.

1. Importance of Large Capacity Outdoor Substation in Super-power System.

The development of the large capacity outdoor substation has been one of the most important factors in the economical distribution of energy over large areas, and in the interconnection of power systems. This interconnection and the development of a super-power system results in a significant saving in operating expenses. Because of the diversity factor of different systems, their peak demands do not occur simultaneously; consequently, each system need not maintain enough generating capacity to supply its peak load; some of this capacity may be obtained from some other system through interconnection. When hydro-electric stations form part of the system, they may be operated at as near full capacity as water supply conditions permit. In thermo-electric stations, the most economical generating units may be operated continuously at, or near, full load, while the less economical units can be employed on short time service. It has been estimated that the saving resulting from interconnection of power systems and the development of a super-power system in New England and New York will amount to over $300,000,000. annually.

2. The Substation Building.

One way in which the large capacity substation differs from the small capacity type is that, in the former, part of the equipment is frequently housed in a building. Among this equipment one will usually find the switchboard and switchboard equipment, such as control switches, metering instruments, indicating instruments, and relays; storage battery for operating oil circuit breakers; motor generator set for charging storage battery; oil pump and oil filter press; water pumps for circulating transformer cooling water; lifting tower; repair space; and rotating equipment, such as synchronous converters or condensers or motor-generator sets. In the larger stations, this building is of fireproof construction. When the low tension voltage is less than about 11000, the low voltage equipment is likely to be mounted in the building, since complete outdoor equipment for such low voltage has not yet been developed.

3. The Switchboard.

The switchboard usually consists of one panel for each feeder circuit, for each bank of transformers, and for each synchronous condenser, synchronous converter, or motor-generator set. Switchboards for battery charging equipment and for station service equipment are frequently mounted apart from the main board.

The main board may be either the vertical or the bench type. If it is the former, it is frequently located about six feet from the wall of the building and is 90 inches high with panels 24 inches wide. On this board, or on the bench board, if such is used, are mounted control switches, indicating lamp receptacles, mimic buses, and indicating instruments. About four feet in the rear of this main board is located an auxiliary board on which are mounted relays, testing switches and recording meters. Conduits carrying control wires, leads from secondaries of instrument transformers, etc., should terminate at the panel where these wires should be located. All conduits should terminate at these proper locations in a steel trough, or run-way, placed at the base and behind the switchboard. This run-way permits wire to be taken to other than the one panel where the conduit ends. At the base of the panels should be located a terminal board on which the wires end and are tagged. The panel wiring is then connected to this terminal board which then provides a ready means for testing.

4. Types of Supports for Large Capacity Substations.

While structures of wooden poles, with steel angles for horizontal members, have been used during periods of scarcity of steel, the almost universal structure for large capacity substations is entirely steel. Concrete poles, and steel pipe frame-work have been used in a few cases, the latter being much more common than the former. For moderate capacity substations, the following advantages are claimed for the pipe frame-work structure: (1) cheaper to install than structural steel; (2) all parts are conveniently kept in stock and are readily available since they are standard switchboard parts; (3) specially trained labor is not required for erection; (4) less time required for erection.

5. Method of Design of Supporting Structure.

a. Requirements for Steel Designer.

When a structural steel support is used, its design should be made by a structural steel designer who is provided by the electrical designer with a sketch showing the type of structure; the dimensions, weights, and spacings of all apparatus to be mounted on structure; the size of all holes necessary for mounting this apparatus; and the necessary clearances between conductors and steel.

b. Loading Data.

The steel design should be based upon rather liberal loading data. For suspension buses, the pull allowed per wire should be about 2000 lb. to 2500 lb., the former being sufficient if the deflection of the towers is taken into account. The wind and ice loads depend upon the location. In northern part of country, common loadings are: 20 lb. per square foot of projected area of conductor, and 30 lb. per square foot of projected area of steel frame for wind load. A common assumption of ice load on conductors is 1/2 inch thickness. The loading must also take into account the dead weight of equipment, conductors and steel.

c. Standard Forms of Design.

As far as is possible, steel supports should be designed in a standard form. Thus, standard girders, towers, etc. should be designed for various sizes, and the complete arrangement made up as much as possible from these standards which may also be used in other installations. This results in much saving both in design and in fabrication of the steel.

d. Protection of Steel Against Corrosion.

All steel work must be given protection against corrosion. In moderate sized stations without regular repair crew, galvanized steel supports may be preferable. A large capacity station, however, has a better appearance if all the equipment and supports are painted a uniform color. A light grey color is best for transformer, oil switch, and lightning arrester tanks as this tends to prevent absorption of heat from the rays of the sun. The design of the steel work should be such as to permit all exposed parts to be painted. All erection and mounting bolts, nuts, and small hardware should, preferably, be galvanized or sherardized. A disadvantage in the use of structural steel which necessarily requires painting is the difficulty of repainting after the station is put in operation. This involves either the necessity of removing from service part of the equipment or of the painter working in dangerous places. In such cases, where the removal of equipment from service is objectionable, the structures should be completely galvanized.

6. Transformer Requirements.

a. Arrangement of Transformers.

Transformers should be arranged in a continuous row, or in two parallel continuous rows. A transfer track should be located parallel to the row of transformers and also between the rows when two rows are used. At right angles with this transfer track, a track is laid to each transformer location, including a location of a spare transformer.

b. Accessories for Transformer Repairs.

Transformers are mounted on wheels at standard gage, which is also the gage of the tracks. The transfer track leads to the repair house which is generally part of the building containing the switchboard, etc. A transfer truck running on the transfer track enables the right angle turn to be made. A lifting tower or hoist of sufficient strength to lift the core of the transformer out of the case is located in the repair house. The transformer track is bolted to a concrete foundation.

When the substation is located near a power station, a hoist may not be necessary. The transfer track can generally be arranged to convey transformers into the power station where the station crane can be made use of in making repairs.

c. Oil Storage Tank.

An oil storage tank should be provided to hold the oil of a transformer, when repairs are being made. A piping system should be installed for draining the oil from any transformer, or oil circuit breaker, to the storage tank; this tank is also used when the oil is being filtered. The tank is generally made of boiler plate, although concrete with a waterproof surface has been used; since the tank holds the oil for only a short time, the leakage is small.

d. Space for Repair Work.

Repair facilities must be made adequate in order to keep the cost of repairs at a minimum. Sufficient space must be provided which is definitely planned for repair work, although this space may be kept at a minimum by removing the transformer tank outdoors when repairs are being made on the core. With adequate repair facilities, delays are avoided and damaged equipment is speedily put back into service.

7. Cooling Systems for Transformers.

a. Self-cooled System.

The two types of transformers used in outdoor substations are the self-cooled and the water-cooled types. In the self-cooled type the heat, developed in the interior of the windings and core, is conducted to the surfaces. The oil in contact with these surfaces becomes heated and rises to the top of the transformer tank; here it flows outward and descends along the sides of the transformer tank through which the heat is radiated into the air. In order to increase the area of the tank exposed to the air, the tank, in the large sizes, is corrugated. In the very large sizes, steel tubes are connected to the tank at the top and bottom, or radiators with a large number of small tubes are similarly connected.

b. Water-cooled System.

In the water-cooled type the transformer temperature is under more definite control. This type has a smooth tank with a copper cooling coil located at the top of the tank. The cooling process differs from that in the self-cooled type in that the heat in the hot oil at the top of the tank is removed by water which flows through the cooling coil. The cooled oil descends along the sides of tank after which it rises again through ducts, removing the heat from the core and coils.

c. Cooling Water Not Recovered.

There are two methods of handling the cooling water: (1) that in which the water is wasted; (2) that in which the water is recovered.

The first method is used when an adequate supply of water is available from a nearby lake or river to which the warm water is returned.

The second method is used when the water supply is from a city service or from deep wells; either a spray pond or a cooling tower may be employed in recovering the cooling water.

d. Cooling Water Recovered by Spray Pond Method.

The spray pond method requires considerable space - about 50 feet by 50 feet for a moderate sized installation. In this method, a series of nozzles, through which the water is sprayed, is mounted over a pond. A circulating pump is necessary to draw the water from the pond and to force it through the transformer cooling coils and through the nozzles.

e. Cooling Water Recovered by Cooling Tower Method.

The two types of cooling towers are: (1) the forced draft cooling tower which is enclosed and has a current of air forced through it in order to increase the evaporation and cooling; (2) the atmospheric cooling tower which is open, permitting free circulation of air from all directions, or the atmospheric cooling tower which is enclosed, depending upon natural draft for circulation of air. The water is pumped to the distributors at the top of the tower where it is broken up into drops in order to expose to the air the largest surface per unit volume. As soon as the outside film of the water drops has been cooled, the drops are collected and again broken up in order to present a new cooling surface to the air. The water flows from one cooling lath to another, flowing over each lath in a thin film and breaking up into a fine spray as it spashes to the next lath. These cooling towers should be made either of steel or of cypress which wood does not deteriorate rapidly in water.

f. Pumping and Circulating System.

An elevated supply tank may be used for holding the water when pumped from the wells. Duplicate pumps should be installed in order to reduce chance of water supply failure. An emergency connection should be arranged, if possible, with a city service, although the rates may be too high to permit general use. Piping connections should be arranged so that either pump can do three things, namely: (1) pump from any well into the supply tank; (2) pump from well through transformer cooling coils; or (3) simply circulate the cooling water from the cold well beneath the cooling towers, through the transformers and back through the towers. In normal operation, one pump should be connected so that it will discharge into the supply tank. A float switch in this tank will keep a constant elevation of water. The other pump normally circulates the water through the transformers and the cooling towers. In order to keep a sufficient supply of circulating water and to make up for evaporation, an automatic float valve may be installed in the cold well to admit water from the supply tank by gravity and to keep it at a given level. For a given load on a transformer, water must be pumped through the cooling coils at a given rate; in order to determine whether the proper rate of flow is being maintained, the transformer should be equipped with flow meters.

If the water in a nearby river is too muddy for use in cooling coils, a shallow well may be dug nearby, thus using the ground as a filter. The expense of pumping will then be less than it would be if a deep well were used, and it will not be much greater than it would be in pumping directly from the river.

Care must be taken to prevent any cooling coils from becoming clogged. A sight flow or other indicating device, showing whether or not the cooling system is operating, should be installed. In order to prevent freezing, all exposed water piping should be lagged in a similar manner to that of steam piping. The water in the cooling coil in idle transformers may be prevented from freezing by energizing the transformer, the heating effect of the magnetizing current being sufficient to keep temperature above freezing; if air containing moisture is present in the tank, this method also prevents condensation of moisture.

g. Operation of Cooling System in Extreme Weather.

An objection to the cooling tower and spray pond method is that in the hottest period of the year when the greatest amount of cooling is needed the relative humidity is highest. Consequently, it becomes difficult to reduce sufficiently the temperature of the cooling water. A more constant temperature of cooling water may be obtained by pumping water from one deep well and returning the hot water to a nearby well, so that it is cooled in the ground.

In severely cold weather, sufficient cooling is obtained from surface evaporation in the basin or cold well beneath the towers. A by-pass valve admits water to one end of the basin and it is withdrawn from the other end. This also eliminates the trouble due to freezing in the towers. In unusually hot weather, cold water may be pumped continuously from the supply well into the circulating system and the same amount of hot water discharged, thus assisting the cooling system in maintaining the cooling water at sufficiently low temperature.

h. Use of Cooling Coil in Self-Cooled Transformer.

It is occasional practice to install a water cooling coil in a self-cooled transformer, in order to increase its capacity at times when an increase is needed. For example, a three phase, 1500 kv-a., 60 cycle, 66000/16500 volts, self-cooled, radiator type transformer, with water cooling coil carrying 8-1/2 gallons per minute, may be operated at 3000 kv.-a. with a temperature rise of 55 degrees centegrade.

The self-cooled transformer is being built in larger capacities than formerly, (up to about 10,000 kv-a.) and its use is increasing. Thus, the expense and trouble of the water supply and cooling system is eliminated. However, the cost is about 25% greater than the water-cooled type and its capacity is likely to be reduced during hot weather because the cooling rate is rather definitely fixed. In the water-cooled type, the rate of flow of water may be varied and, consequently, a more even temperature can be maintained throughout the year with no reduction in capacity.

8. Grounds and Ground Connections.

a. Need of Ground Connections.

The problem of ground connections should be given careful attention in every substation in order to reduce the hazard to the operators. Live parts of the circuit may come in contact with frames, or cases of equipment, or with steel supports, unless these frames, cases, and supports are properly grounded. Also voltages may be induced in these frames and supports, due to proximity, without contact, with current carrying parts.

b. Method of Installing Ground Connections.

The ground connections should be installed before the foundations for apparatus are made. A satisfactory method is to drive one inch or larger steel pipes as far as possible into the bed of each of the excavations for the foundations. These ground pipes should be extended above the top of foundations, and should be interconnected by lateral pipes laid in trenches and connected by T connections to the ground pipes. All pipe connections should be carefully made; contact surfaces in T connections and couplings should be clean and drawn up tightly so that the ends of the pipes meet in the couplings.

c. Method of Connecting Equipment to Ground Connections.

After the electrical equipment is installed, connections are made from all parts to be grounded to the ground pipes extending above the foundations. A satisfactory method of making a ground connection, when the part to which connection is made is a flat surface, such as a flat portion of a steel structure, is a pipe flange connected to pipe and bolted to the structure. For connection to electrical equipment, the end of the pipe may be flattened, a hole drilled and the end bolted to the equipment. A wire connection may be made to the ground pipe by means of a lug and pipe cap.

The resistance of the ground connection should be measured when it is complete, and followed by measurements at regular intervals during the operation of the substation. Records of these measurements will indicate when a change in the resistance occurs and will show the condition of the ground connections.

9. General Design Features of the High Voltage Large Capacity Substation.

a. 220,000-volt Large Capacity Substation.

In Chapter 6 are given the design features of outdoor substations in general. These features also apply to the high voltage, large capacity substation; but features will be discussed in this section which apply particularly to this type of substation. For a definite problem, the design features of a 220,000-volt, large capacity substation will be considered. These features, however, will apply to high voltage, large capacity substations in general.

b. Cardinal Principle in Design.

With further development of the 220,000-volt transmission system the substation at this voltage will become much more common. Because of the large spacing required for conductors and equipment at this voltage, the substation will be almost invariably of the outdoor type. Instead of flexibility of arrangement, the cardinal principle in the design of such a substation should be strength of equipment and simplicity of arrangement.

c. Continuity of Service Resulting from Strength and Simplicity.

The strength of the equipment and simplicity of the arrangement of the apparatus should be such that failures and interruptions to service are a minimum. Because of the great cost of oil circuit breakers, transformers, etc., for this voltage, generally, spare equipment will not be provided in order to insure continuity of service. Such service is more practically insured by adequate equipment and simplicity of its arrangement. Since the service performed by these 220,000-volt substations will be to feed into a lower voltage system, such as a 66000 or 110000-volt system, dependence can be placed upon the reserve capacity of local generating stations which feeds this lower voltage system - thus occasional interruptions in the 220000-volt substation will be taken care of.

d. Protection against Short Circuits.

One of the principal problems in the design of a 220000-volt substation is to provide protection from short circuit stresses. In order to limit short circuit currents, transformers for 220000 volts are built with high reactance. Both transformers and oil circuit breakers must have high mechanical strength and adequate insulation in order to withstand the stresses resulting from short circuits. The extent of the disturbance due to a short circuit, or to other fault on the system, should be minimized by an adequate system of relay protection which sectionalizes and disconnects faulty equipment, lines, or feeders.

e. Switching and Switching Equipment.

Another of the principal problems of the 220000-volt substation is in switching and switching equipment. Adequate switching equipment has been developed, based upon the principles used for lower voltage equipment. The problem of switching is largely connected with the amount of current handled. It can be shown that an economical capacity of a 220000-volt circuit is about 100000 kv-a. Since at present the largest three phase transformers are about 50000 kv-a., and the largest single phase transformers are about 35000 kv-a., two of the former, or one three-phase bank of the latter, would be required per circuit. With such large blocks of power, the currents on the low tension side of transformers would be such that they could be interrupted only with great difficulty. Consequently, the station design and arrangement should be such that all line switching will be done on the high tension side of transformers.

f. Transformer Connections.

Transformers for 220000 volts have but one high tension bushing per phase, resulting in less cost and less possibility of failure than if two bushings were used. The other end of each phase of the high tension winding is permanently grounded to the transformer core. The transformers are thus Y Y connected with neutrals grounded directly which gives the advantage of a more stable voltage and a more positive operation of the relay protection system. The resistance in the ground connection, used in some lower voltage systems for limiting the short circuit current resulting from a ground on one phase, is not needed in the 220000-volt system in which the short circuit current would be comparatively small and would not cause excessive mechanical stresses.

g. Elimination of Lightning Arresters.

The use of lightning arresters for protection against high voltage is not current practice for 220000-volt circuits. The reasons for elimination of the lightning arrester are: (1) that the lightning arrester is practically of no use in case of a direct stroke; (2) that the insulation of the line, having a normal operating voltage of 220000 volts, can withstand induced lightning disturbance, the voltage of which, it is believed, is of the same order, approximately, as the operating voltage; (3) that the solidly grounded neutral prevents abnormal rise of voltage resulting from surges due to switching. Therefore, since the insulation of the line and the equipment can withstand the highest voltages that are likely to occur in practice, the lightning arrester is not needed. It is believed that protection against high frequency disturbances also can be provided by adequate insulation of equipment. This practice of eliminating the lightning arrester is becoming more common even at lower voltage substations, as for example, the 110000-volt system of the Mississippi River Power Company, where it is found that the cost of maintenance of the lightning arresters is greater than the cost of repairing the damage due to lightning and other disturbances.

h. Use of Synchronous Condensers.

Since synchronous condensers are essential for voltage regulation and power factor correction on long transmission lines, they must have a place in the 220000-volt substation. Present transmission line practice, especially on new systems, is operation at constant voltage both at the sending and at the receiving ends of a line, or at all parts of a system. By means of automatic voltage regulators, the generator voltage, at the sending end of the line, is held constant either at the same or at a higher voltage than that at the receiving substation end. Voltage regulation and power factor correction are obtained by variation of condenser excitation:- over-excitation at times of heavy load resulting in a leading current taken by the condenser; under-excitation at times of light load resulting in a lagging current taken by the condenser. The leading current results in a rise in voltage which neutralizes the fall in voltage, due to heavy load; and the lagging current results in a fall in voltage which neutralizes the rise in voltage, due to light load.

These condensers are usually not designed to operate at full capacity with lagging current, but may be specially designed to operate with lagging current up to 75 percent of their full load rating. Each 220000-volt line, leading to the substation, would be provided with a synchronous condenser which would be connected to a tertiary winding on the power transformer connected to this line. This tertiary winding would be arranged for the same voltage as the condenser as, for example, 11000 or 13200, although high voltage condensers may be developed. The transformer should also have a lower voltage winding, such as 3300 volts, for starting the condenser, thus eliminating the need of a starting compensator. It is common practice to install synchronous condensers with capacities not exceeding about 60 percent of the kv.-a. of the load at 0.8 power factor. The capacity of the condenser is determined by (1) the power factor of the load; (2) the load factor of the load; (3) the characteristics of the transmission line; (4) the extent of the voltage regulation desired for the line; and (5) the amount of power factor correction desired. A complete economic study of the influence of these various factors in determining the correct capacity of the synchronous condenser is beyond the scope of this thesis.

i. General Arrangement.

In every case, local conditions will greatly influence the design of the substation. Consequently, a complete general arrangement can not be given. A single high tension 220000-volt bus will be found preferable in many cases. This bus should be provided with sectionalizing oil circuit breakers with relays set for faster operation than those on the line breakers. The low tension bus, 66000 or 110000 volts, preferably should be of the ring or double type in order to provide greater flexibility in operation. This bus may be provided with sectionalizing reactances in order to limit short circuit currents.

j. Description of First 220000-volt Outdoor Substation.

In order to complete this discussion of the 220000-volt substation, a brief description will be given of the first outdoor substation constructed for 220000 volts. This substation, the Vaca Substation of the Pacific Gas and Electric Company, is the terminus of the double 220000-volt circuit from the Pit River No. 1 Station of that company.

The capacity of this substation is 100,000 kv.-a. with two banks of three single phase transformers. One spare transformer is provided. Each of the seven transformer units is rated at 16,667 kv.-a. and is of the auto-transformer type:- the first of this type constructed for 220000 volts. The transformers are of the oil conservator type, with a single oil filled high tension bushing. The other end of the high tension winding is permanently grounded within the transformer tank.

The oil circuit breakers used in this installation are similar to those used on lower voltages except that the dimensions are greater. Instead of providing duplicate or spare oil circuit breakers, air-break switches are used to by-pass the oil circuit breakers when repairs, adjustments, or inspection are necessary.

Two 20,000 kv.-a. synchronous condensers are installed in the substation for voltage regulation. The transformers have a tertiary winding at 11000 volts for operation of these condensers. They also have a 3300-volt tap for starting the condensers. The 11000 and 3300-volt equipment is mounted in weatherproof compartments.

The purpose of this substation is to reduce the line voltage from 220000 to 110000 volts at which the energy is distributed over comparatively short distances.

IX. COSTS OF OUTDOOR SUBSTATIONS.

1. Cost Data.

The cost of an outdoor substation involves many factors, two important ones being local conditions, and the function and design of the station. Cost data on actual installations are available in the technical journals, and in "Mechanical and Electrical Cost Data" handbook by Gillette[1] and Dana.

2. Comparison of Costs of Indoor and Outdoor Substations.

A comparison of costs of indoor and outdoor substations is difficult, due to the fact that similar substations of each type are seldom installed under similar conditions. Estimates of costs indicate that, for stations of 10000 kv.-a., and 66000 volts, the saving in cost in favor of the outdoor substation is, approximately, from 10 to 15 percent. For larger capacities and higher voltages, as 110000 volts, for example, the saving is, approximately, from 20 to 25 percent. If the station contains much bus and switching equipment, the saving amounts to, approximately, 30 or 35 per cent. Under some conditions, particularly for very high voltages, the saving may amount to 50 per cent.

3. Costs for 33000 to 2300-volt Substations.

An examination of cost data indicates a wide variation in costs for substations of the same capacity, type, and voltage, due largely to local conditions. For example, the total costs of three phase, steel tower, substations for 33000 to 2300 volts for various capacities have the following approximate values:

Capacities in kv.-a.	Approximate total cost in dollars per kv.-a.
45	from 20 to 36
60	" 16 " 30
75	" 15 " 24
90	" 13 " 22
120	" 11 " 20
150	" 9 " 18
300	" 8 " 16
600	" 6 " 15
1000	" 5 " 14
2000	" 4 " 12

4. Cost Data Curves.

The compilation of cost data for substations of all types, capacities, and voltages cannot be given here. Some available published cost data are presented, in the form of curves, for substations of a few common types and voltages. This data is only approximate, and is for substations with the following equipment:

a. Cost Data, Sheet 1.

Curve 1 gives costs for substations with high tension disconnecting fuses; transformer mounted on wooden pole; and low tension equipment in enclosed switch house.

Curve 2 gives costs for substations with high tension air-break switch, and fuse; three single phase transformers in three phase connection mounted on wooden poles; low tension equipment in enclosed switch house.

b. Cost Data, Sheet 2.

Curve 1 gives costs for substations with high tension air-break switch, choke coils, and fuses; three single phase transformers mounted on platform attached to steel structure; aluminum cell lightning arrester; low tension equipment in enclosed switch house. The steel frame-work is painted and is three feet wide with transformer connections mounted on brackets outside of the structure.

Curve 2 gives costs for substations similar to those involved in Curve 1 except that the steel frame-work is galvanized and is nine feet wide, with transformer connections on horizontal supports mounted inside of the steel structure.

c. Cost Data, Sheet 3.

Curve 1 gives costs of substations with high tension air-break switch, choke coil, and fuses; three single phase transformers mounted on concrete slab on the ground; aluminum cell arrester; low tension equipment in switch house; steel structure galvanized.

Curve 2. gives cost of substations with high tension disconnecting switch, choke coil, and oil switch; three single phase transformers mounted on a concrete slab on the ground; aluminum cell arrester; low tension equipment mounted in a meter house; steel structure galvanized.

d. Cost Data, Sheet 4.

Curve 1 gives transformer costs per kv.-a. of a single phase transformer for 16500 volts high tension and 110 - 220 volts low tension.

Curve 2 gives station equipment costs per kv -a. including the cost of pole structure for outdoor substations of the same voltage as that of transformers the cost of which is given in Curve 1.

e. Cost Data, Sheet 5.

Curve 1 gives transformer costs per kv.-a. for three single phase transformers for 16500 volts high tension and 110 - 220 volts low tension.

Curve 2 gives station equipment costs per kv.-a. including the cost of pole structure for outdoor substations of the same voltage as that of transformers the cost of which is given in Curve 1.

f. Cost Data, Sheet 6.

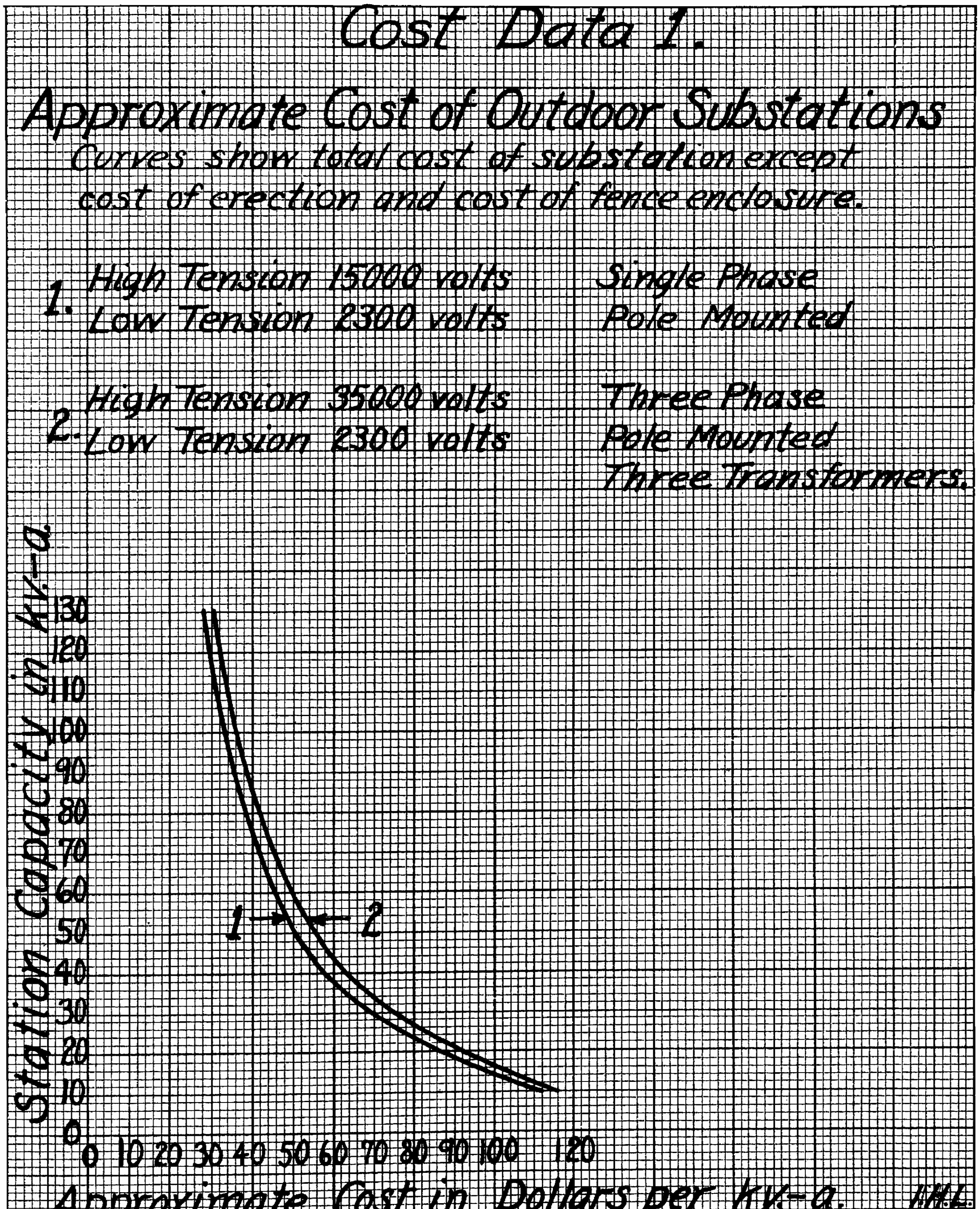
Curve 1. gives transformer costs per kv.-a. for three single phase transformers for 16500 volts high tension and 2200 volts low tension.

Curve 2 gives station equipment costs per kv.-a. including the cost of steel tower structure for outdoor substations with voltages of 16500 on high tension side and 2200 on low tension side.

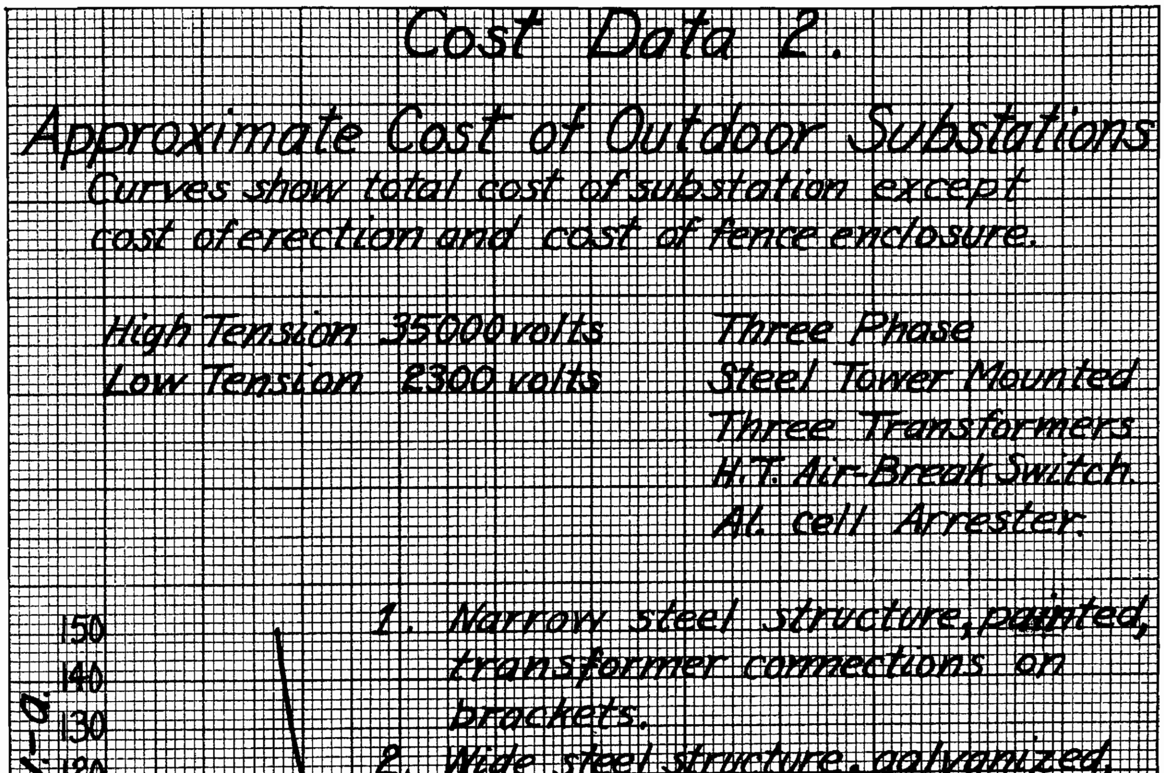
g. Cost Data, Sheet 7.

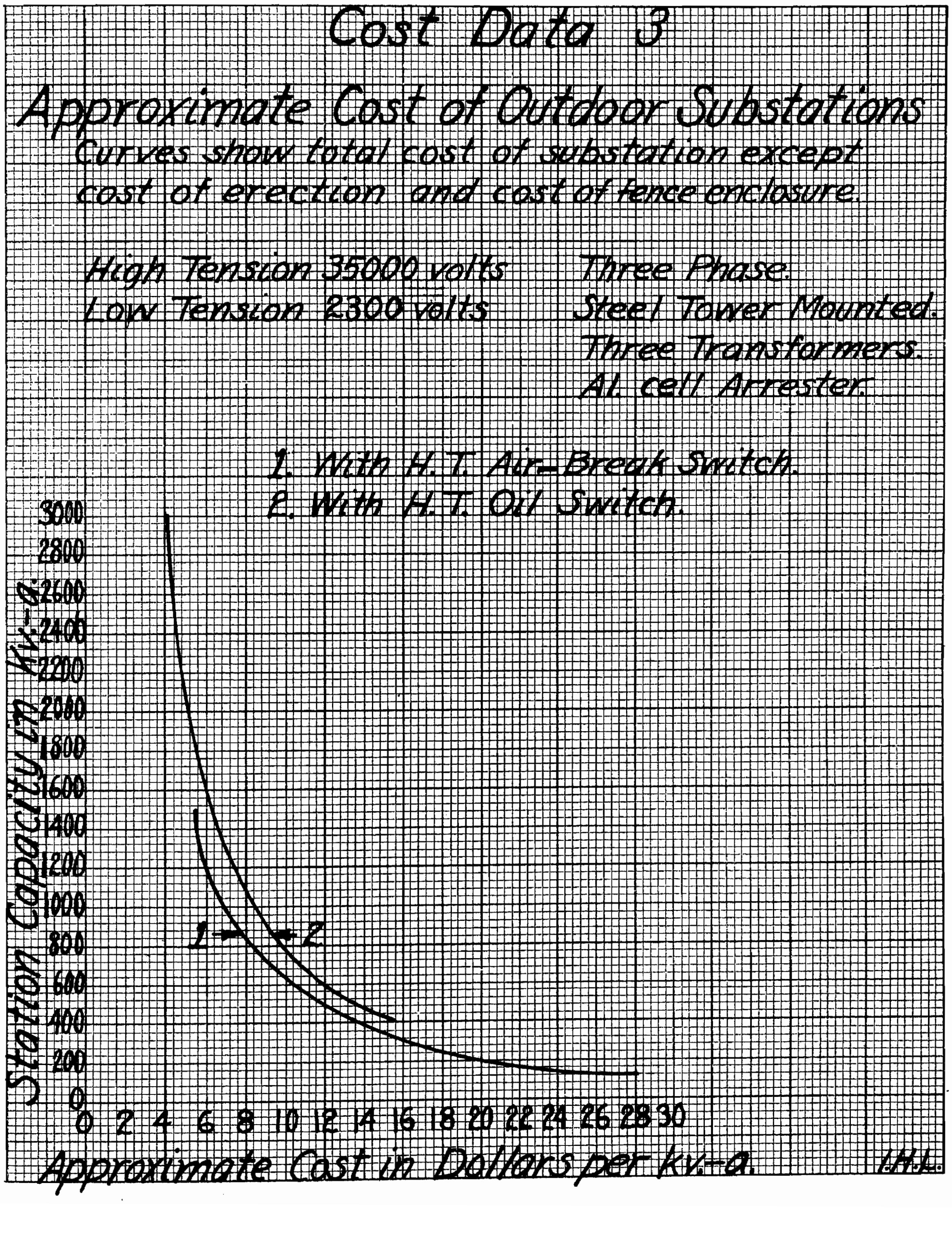
Curve 1 gives transformer costs per kv.-a. for three single phase transformers for 35000 volts high tension and 2200 volts low tension.

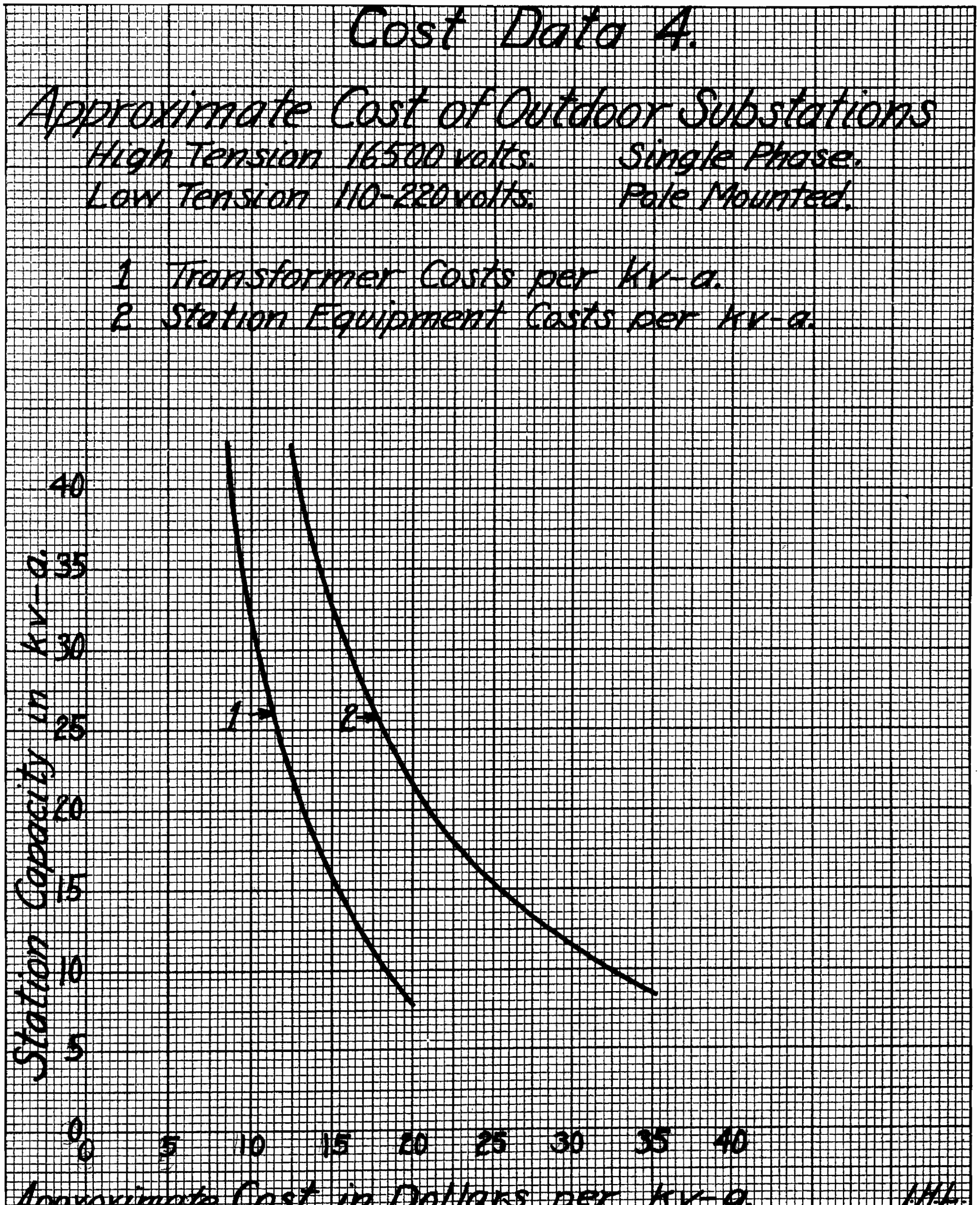
Curve 2 gives station equipment costs per kv.-a. including the cost of pole structure for outdoor substations with voltages of 35000 on high tension side and 2200 on low tension side.

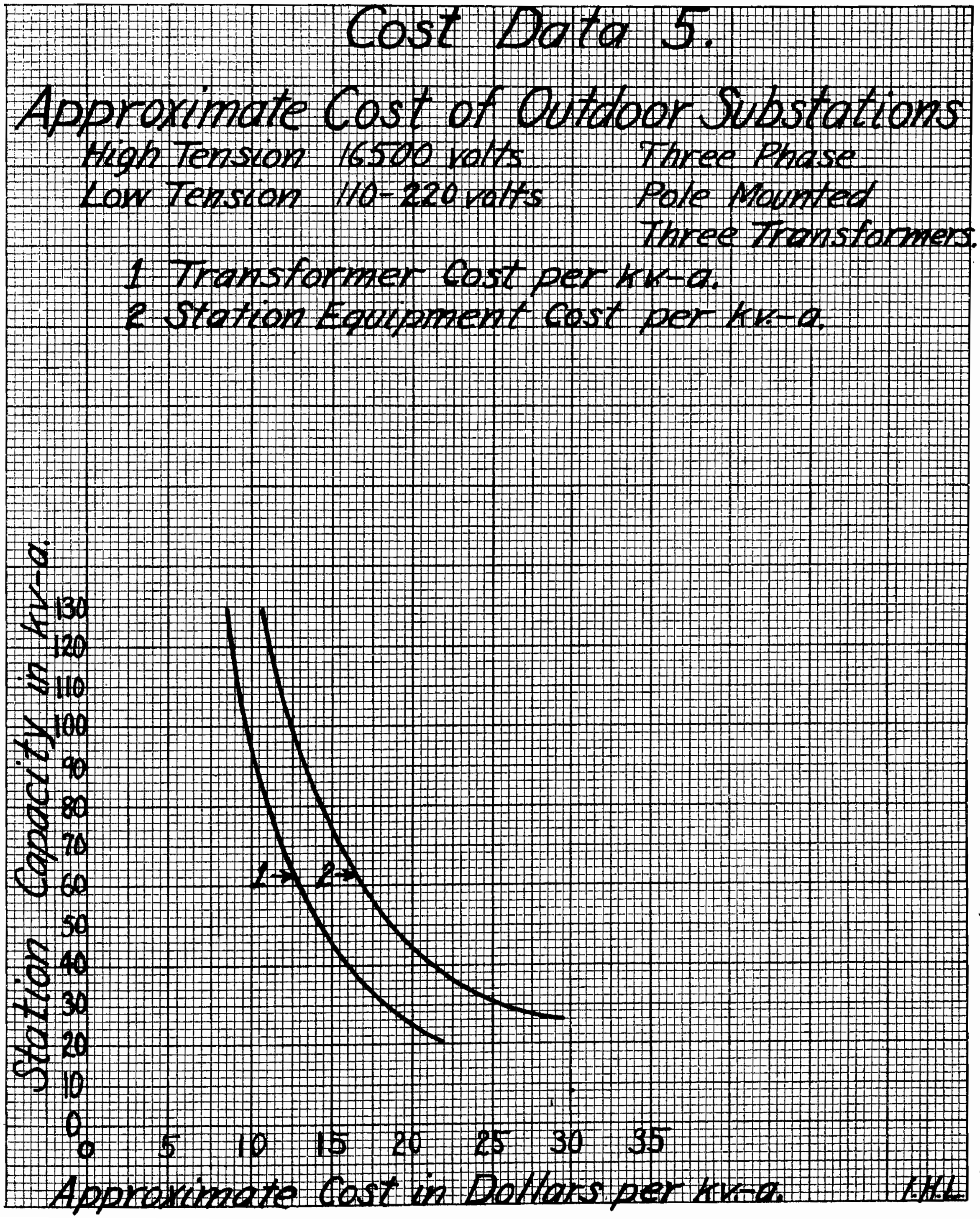


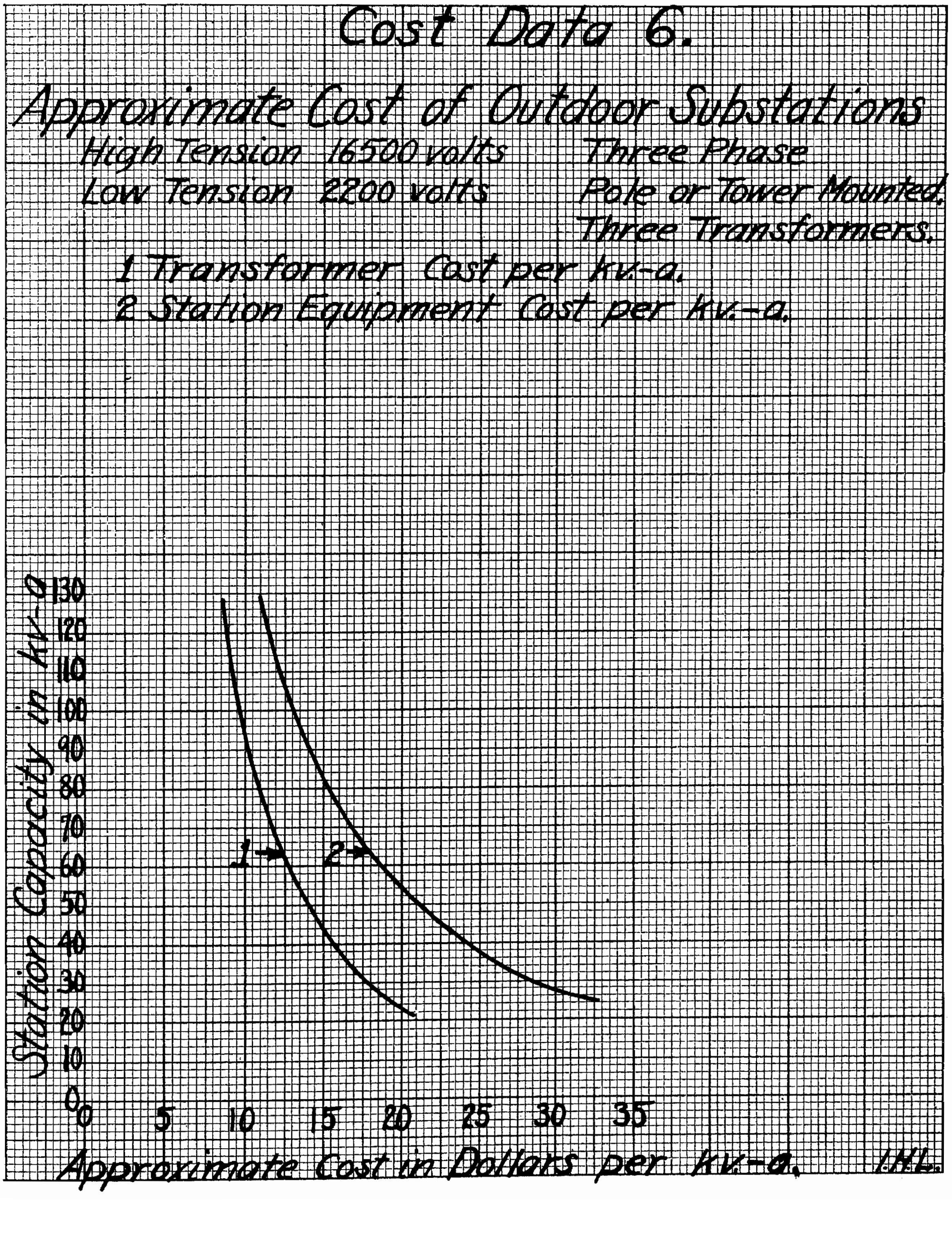
Cost Data 1.
Approximate Cost of Outdoor Substations
Curves show total cost of substation except cost of erection and cost of fence enclosure.
1. High Tension 15000 volts
Low Tension 2300 volts
Single Phase
Pole Mounted
2. High Tension 35000 volts
Low Tension 2300 volts
Three Phase
Pole Mounted
Three Transformers.
Station Capacity in kv.-a.
0 10 20 30 40 50 60 70 80 90 100 110 120 130
1
2
0 10 20 30 40 50 60 70 80 90 100 120
Approximate Cost in Dollars per kv.-a.
I.H.L.

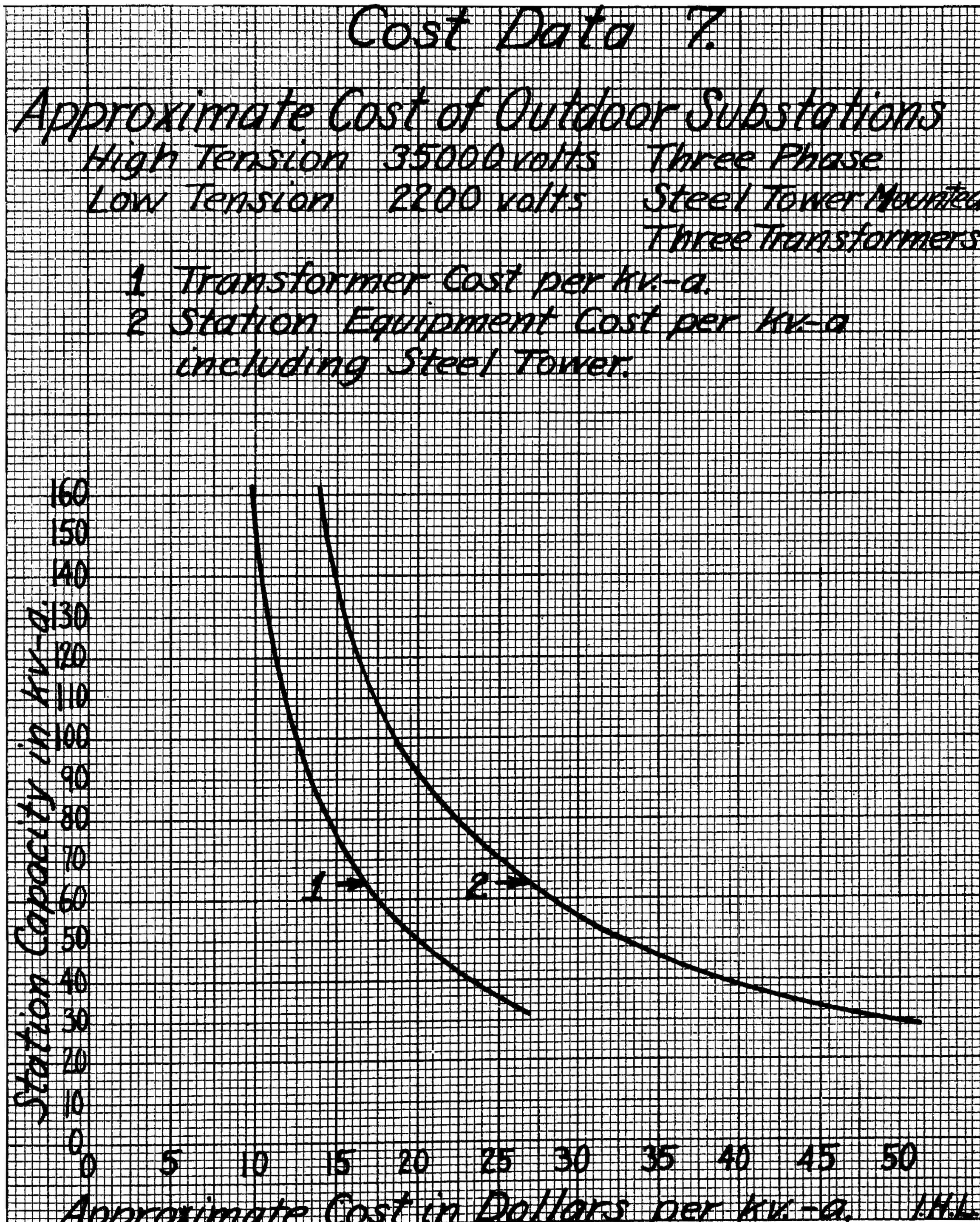

Cost Data 2.
Approximate Cost of Outdoor Substations
Curves show total cost of substation except cost of erection and cost of fence enclosure.
High Tension 35000 volts
Low Tension 2300 volts
Three Phase
Steel Tower Mounted
Three Transformers
H.T. Air-Break Switch.
Al. cell Arrester.
1. Narrow steel structure, painted, transformer connections on brackets.
2. Wide steel structure, galvanized, transformer connections within structure on horizontal members.
Station Capacity in kv-a.
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
0 5 10 15 20 25 30 35 40 45 50 55 60
Approximate Cost in Dollars per kv-a.
I.H.L.


Cost Data 3
Approximate Cost of Outdoor Substations
Curves show total cost of substation except cost of erection and cost of fence enclosure.
High Tension 35000 volts
Low Tension 2300 volts
Three Phase.
Steel Tower Mounted.
Three Transformers.
Al. cell Arrester.
1. With H.T. Air-Break Switch.
2. With H.T. Oil Switch.
Station Capacity in kv.-a.
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
2
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Approximate Cost in Dollars per kv.-a.
I.H.L.


Cost Data 4.
Approximate Cost of Outdoor Substations
High Tension 16500 volts. Single Phase.
Low Tension 110-220 volts. Pole Mounted.
1 Transformer Costs per kv-a.
2 Station Equipment Costs per kv-a.
Station Capacity in kv-a.
0
5
10
15
20
25
30
35
40
1
2
0
5
10
15
20
25
30
35
40
Approximate Cost in Dollars per kv-a.
HHL


Cost Data 5.
Approximate Cost of Outdoor Substations
High Tension 16500 volts
Low Tension 110-220 volts
Three Phase
Pole Mounted
Three Transformers.
1 Transformer Cost per kv-a.
2 Station Equipment Cost per kv-a.
Station Capacity in kv-a.
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
0
5
10
15
20
25
30
35
Approximate Cost in Dollars per kv-a.
I.H.L.


Cost Data 6.
Approximate Cost of Outdoor Substations
High Tension 16500 volts
Three Phase
Low Tension 2200 volts
Pole or Tower Mounted.
Three Transformers.
1 Transformer Cost per kv.-a.
2 Station Equipment Cost per kv.-a.
Station Capacity in kv-a
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
0
5
10
15
20
25
30
35
Approximate Cost in Dollars per kv.-a.
I.H.L.


Cost Data 7.
Approximate Cost of Outdoor Substations
High Tension 35000 volts Three Phase
Low Tension 2200 volts Steel Tower Mounted
Three Transformers
1 Transformer Cost per kv.-a.
2 Station Equipment Cost per kv.-a
including Steel Tower.
Station Capacity in kv.-a.
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
0
5
10
15
20
25
30
35
40
45
50
Approximate Cost in Dollars per kv.-a.
I.H.L.

X. OUTDOOR SUBSTATION STANDARD FORMS.

1. Standardization of Parts of Substations.

In Section 9 of Chapter VI it was stated that standardization of outdoor substations consists largely of standard design of parts of large stations, and standard substation in small sizes. The result of the development of standard parts is a large saving in cost of equipment, cost of construction, and cost of maintenance: equipment can be purchased in large quantities, with the assurance that it will be applicable in substations to be constructed in the future; construction men become familar with the erection of parts of the equipment and can assemble in less time substations in which these parts are the same as in substations previously constructed; when several substations in a power system have similar parts, the amount of equipment kept on hand for repairs and maintenance is much less.

2. Standard Bus Wiring.

A few forms of standard bus wiring are given in the following sheets. These forms are for high tension substation bus wiring of the non-rigid type of bus supported by suspension insulators. These details were developed by the writer for substations of the New England Power Company.

Sheet No. 5 shows details of dead end of bus on a steel structure with a connection from the bus to some equipment located beneath the structure. Standard forms of equipment are specified.

Sheet No. 6 shows a similar dead end connection and similar tap from the bus to some equipment. In addition, a turnbuckle is shown which is needed in one end of each bus in order that the tension in the bus may be adjusted with change of temperature.

Sheet No. 7 shows details of connecting bus to a General Electric Company Type LG-119 air-break, or disconnecting switch, supported on the steel girder that supports the bus. The insulator next to the steel girder must be moved out far enough to give sufficient clearance between it and the base of the switch.

Sheet No. 8 shows a similar connection to an air-break switch with the addition of a choke coil, with details of the connections from bus to choke coil and from choke coil to switch.

Sheet No. 11 is similar to Sheet No. 5 except that the dead end is connected to a wooden pole structure with steel cross-arm, and a special roller clevis is used in connecting the bus to the insulators. When this clevis is used the bus wire need not be cut, thus eliminating a joint in the electric circuit. It also gives greater ease in erection.

Sheet No. 12 shows a dead end connection similar to that of Sheet No. 11 with the addition of an eye bolt arranged to perform the duty of a turnbuckle.

Sheet No. 13 shows a dead end connection similar to that of Sheet No. 12 except that a turnbuckle with eye and clevis is used instead of the eye bolt. The arrangement shown on Sheet No. 12 is preferable because the tap connection to equipment is nearer the supporting structure.

Sheet No. 14 shows details of connections from bus to a suspension disconnecting switch, and from the switch to the suspension insulators, and the tap to equipment.

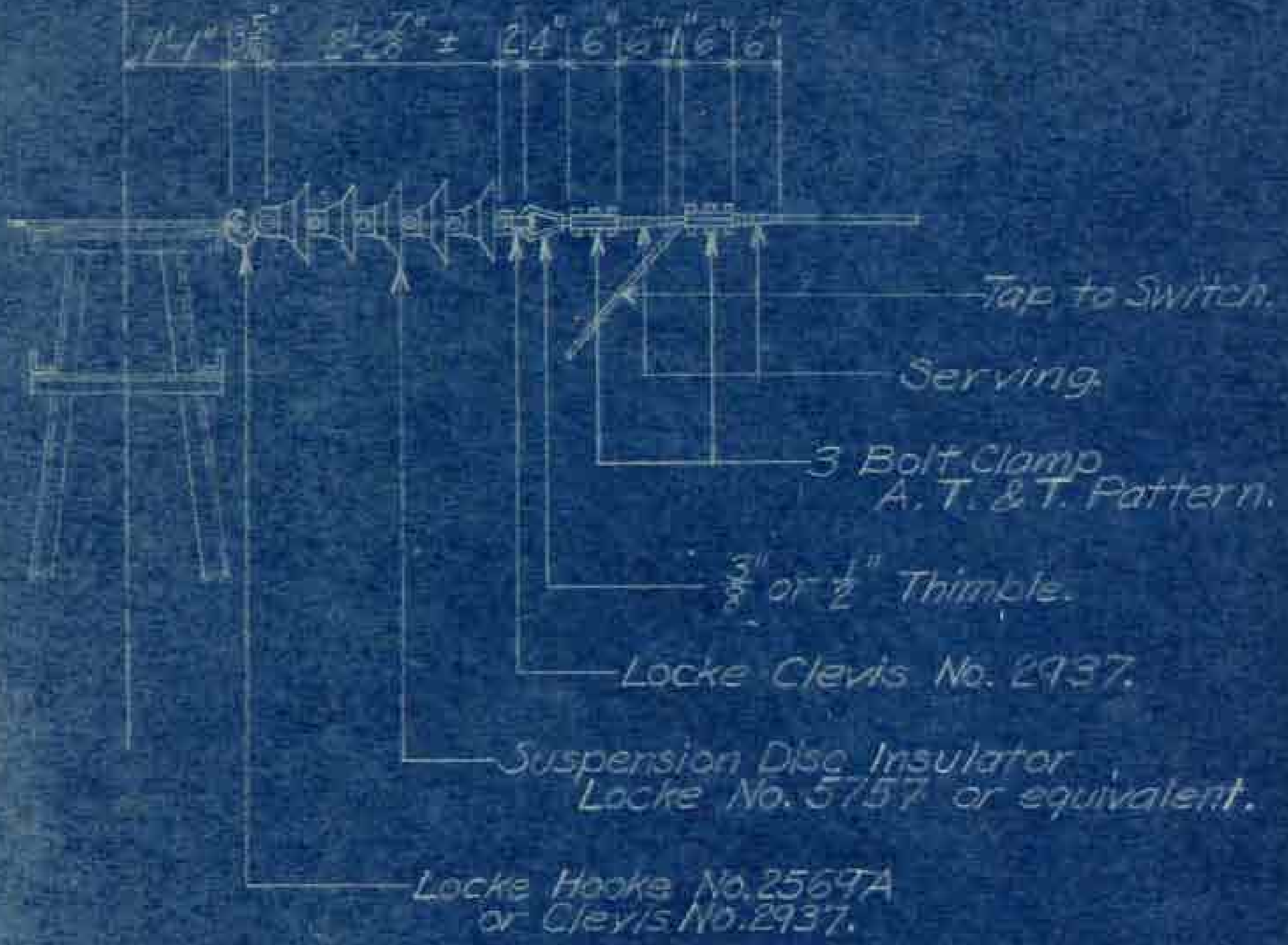
Sheet No. 15 shows details of connections of a suspension disconnecting switch similar to that of Sheet No. 14 except that the connection between the disconnecting switch and the bus insulators is shorter and simpler.

Sheet No. 16 shows details of connections from bus to choke coil and from choke coil to bus insulators using bus wire and three-bolt clamps for the latter connection.

Sheet No. 17 shows details of dead end connection to middle of steel girder, instead of to top as shown in Sheet No. 7. A tap is made to an air-break switch mounted on the steel girder. The connection from bus insulators to girder is by cable, and three-bolt clamps.

The above groups of standard detail designs are presented as an example of standardization of parts of a substation. Similar groups have been prepared for other parts of a substation as for example: (1) steel cross-arms for supporting insulators, and various types of air-break switches and fuses; (2) steel girders and towers; (3) concrete foundations for towers, transformers, oil switches, lightning arresters, and metering outfits of various types; (4) wiring diagrams of connections for all parts of the equipment as, for example, for relays, instruments, control circuits, etc.; (5) types of lighting fixtures and fittings used in substation lighting.

In the design of a new substation, the general arrangement is determined by local conditions and requirements; while the detail design of many of the parts of the equipment is that of the standard details as previously designed.



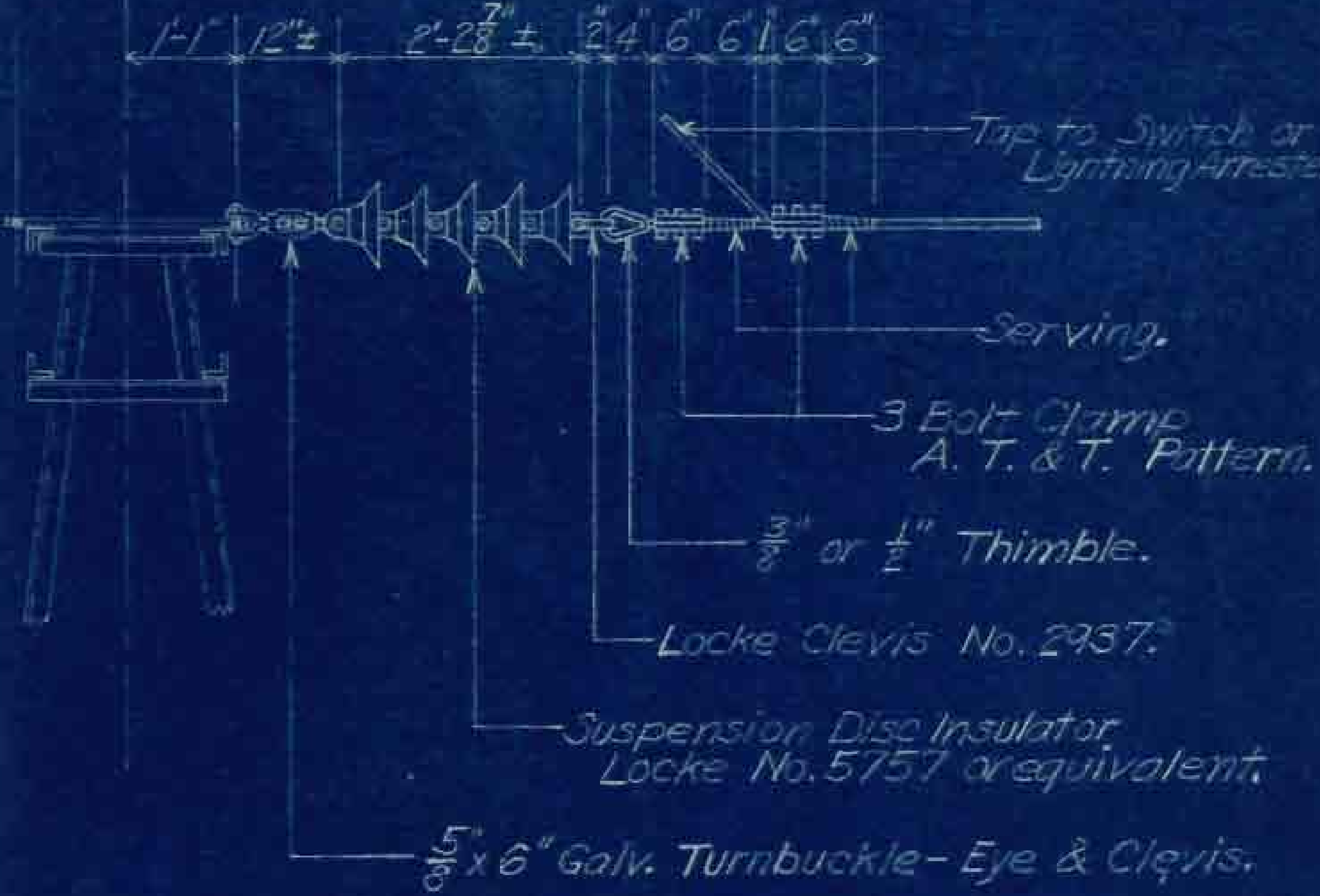
DEAD END AT STEEL TOWER
66000-VOLT SUBSTATION BUS WIRING.

NOTES:
1. Omit tap to switch when it is not required.
2. For 110,000 V. installation use 7 discs.
3. For 11,000 V. & 22,000 V. " " 2 " .

STANDARD BUS WIRING
SHEET No. 5.

SCALE $\frac{1}{8}$" = 12" DATE: FEB. 7, 1923
OUTDOOR SUBSTATIONS
T.H. LOVETT.

E-796-1



DEAD END WITH TURNBUCKLE
66000 VOLT SUBSTATION BUS WIRING.

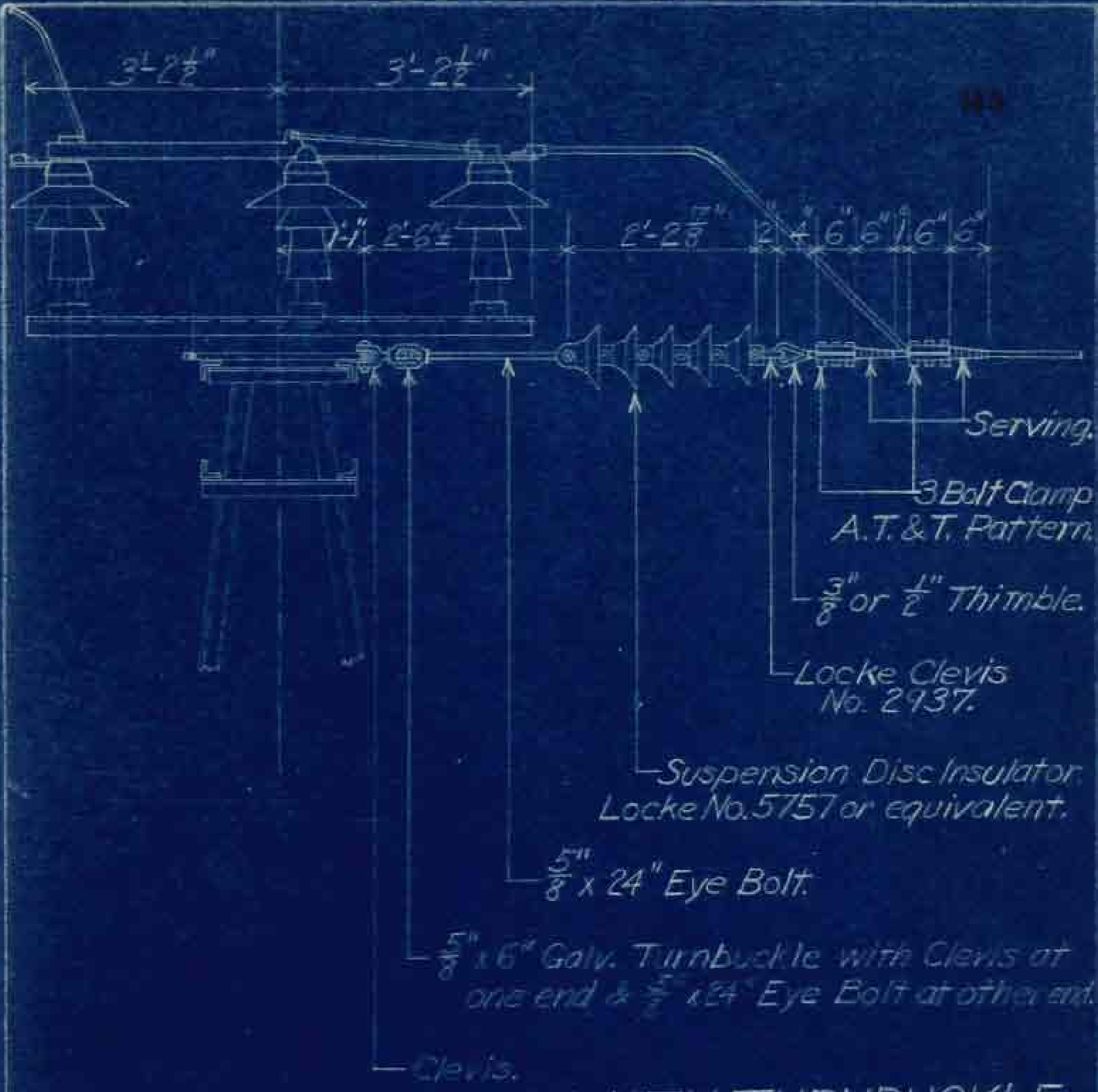
NOTES:

1. Omit tap to Switch or Lightning Arrester when it is not required.
2. For 110,000 V. installation use 7 discs.
3. For 11,000 V. & 22000 V. " " 2 " .

STANDARD BUS WIRING
SHEET No. 6.

SCALE: 1/2" = 12" DATE 7-17-23.
OUTDOOR SUBSTATIONS.
I.H. LOVETT.

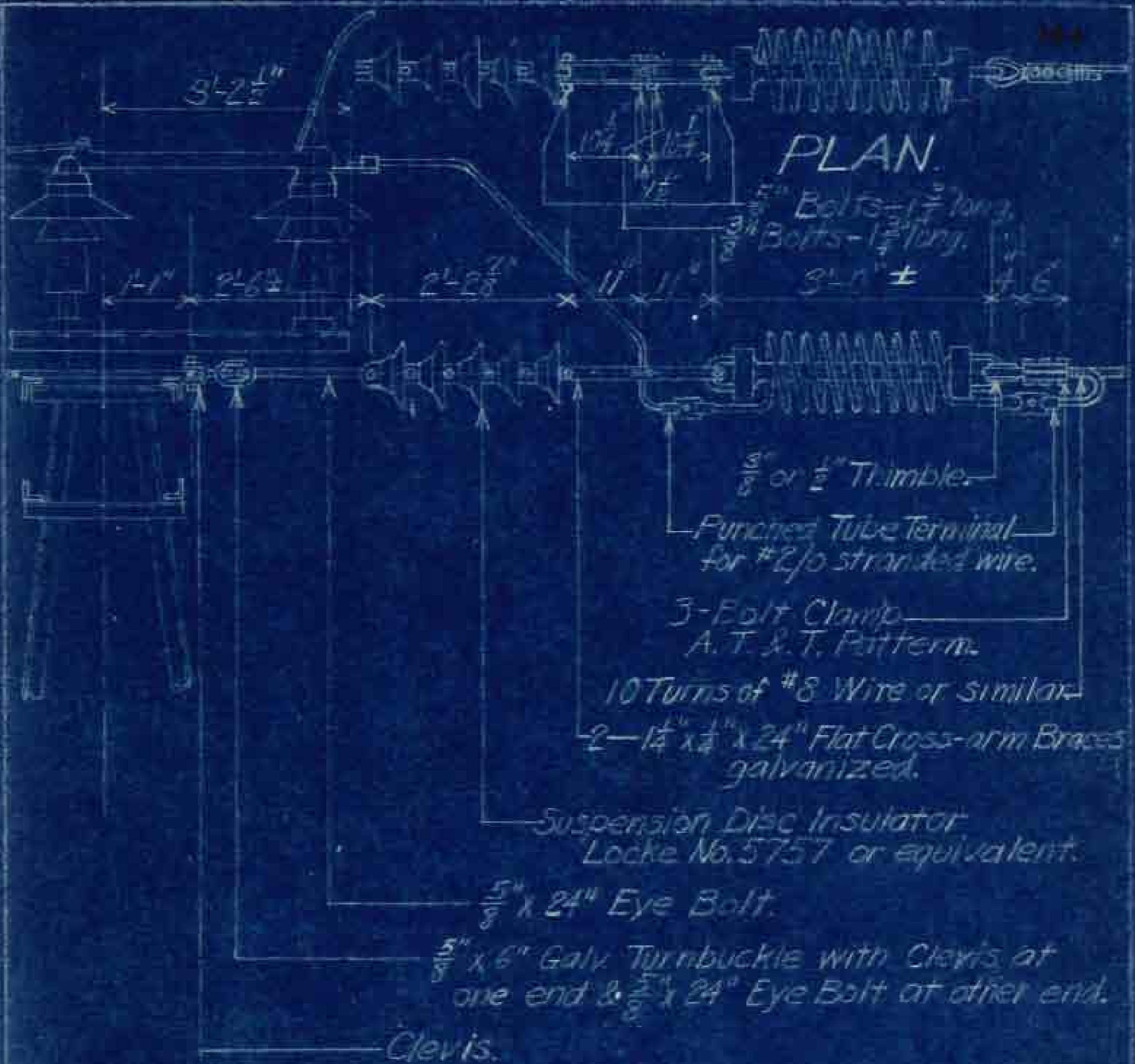
E-797-1



AIR BREAK SWITCH WITH TURNBUCKLE
66000 VOLT SUBSTATION BUS WIRING

STANDARD BUS WIRING
SHEET No. 7.
SCALE ½" = 1'-0"   DATE: 6-2-23
OUTDOOR SUBSTATIONS
I.H. LOVETT.

E-798-1

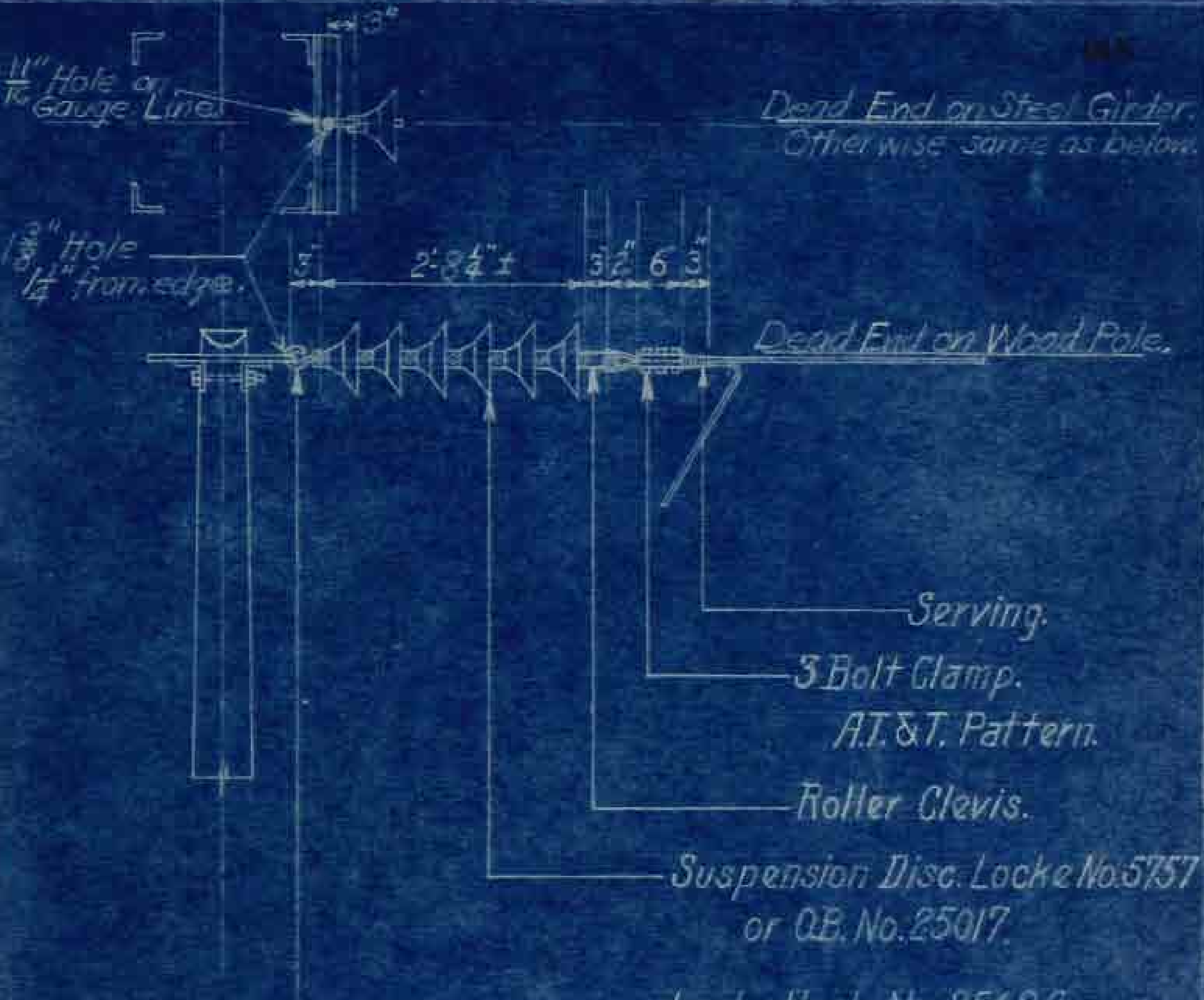


CHOKE COIL ASSEMBLY.
66000 VOLT SUBSTATION BUS WIRING.

STANDARD BUS WIRING
SHEET No. 8.

SCALE: 1/2" = 1'0" DATE: 3-2-23
OUTDOOR SUBSTATIONS
I.H. LOVETT.

E-799-1



Dead End with Hook for 66000-Volt Substation Bus Wiring.

Notes.

1. For 110,000 Volt installations use 7 discs.
2. For 11,000 & 22,000 Volt installations use 2 discs.

STANDARD BUS WIRING

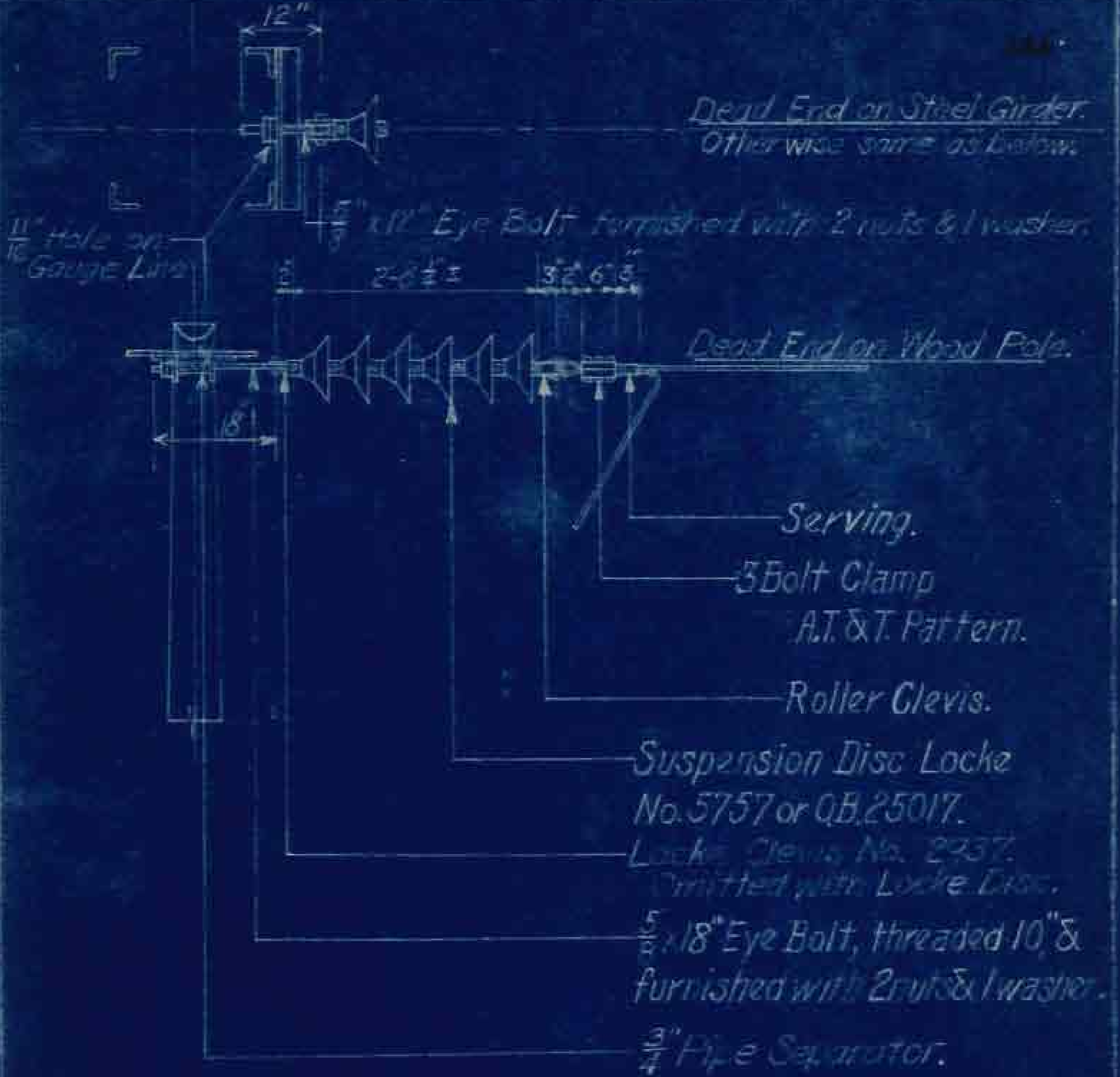
SHEET NO. 11.

SCALE: $\frac{1}{2}$"=1'-0"   DATE: 3-2-23

OUTDOOR SUBSTATIONS

I. H. LOVETT.

E-1182-1



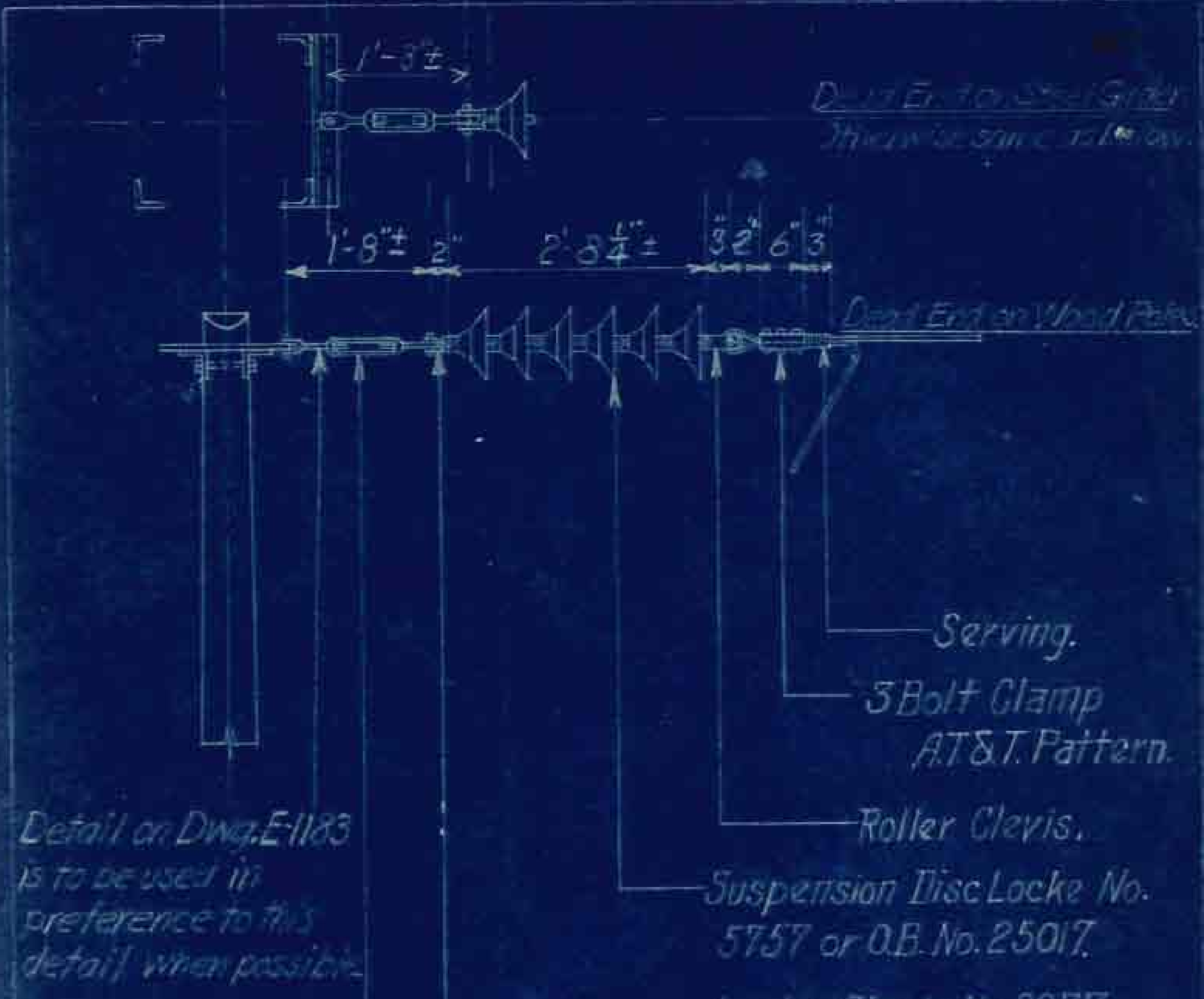
Dead End with Eye Bolt for 66000V Substation Bus Wiring.

Notes.
1. For 110,000 Volt installations use 7 discs.
2. For 11000 & 22000 Volt installations use 2 discs.

STANDARD BUS WIRING
SHEET NO. 12

SCALE $\frac{1}{2}$"=1'-0" DATE: 3-2-23
OUTDOOR SUBSTATIONS
I.H. LOVETT.

E-1183-1



Dead End with Turn Buckle for 66000 V. Substation Bus Wiring

Notes.

1. For 110,000 Volt installations use 7 discs.
2. For 11,000 & 22000 Volt installations use 2 discs.

STANDARD BUS WIRING

SHEET NO. 13

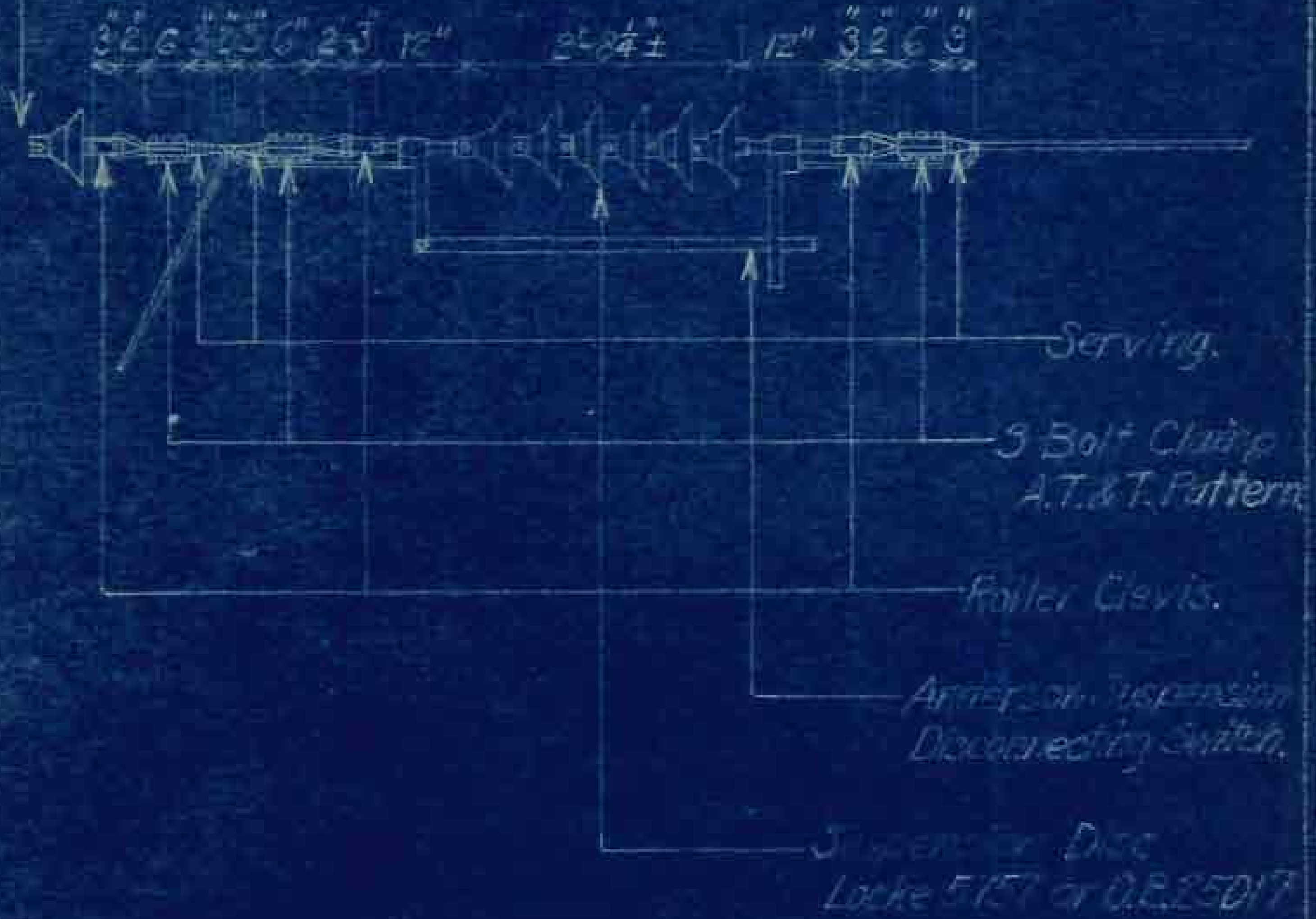
SCALE: $\frac{1}{2}$" = 1'-0" DATE: 3-2-23

OUTDOOR SUBSTATIONS.

I. H. LOVETT.

E-1184-1

For details of Insulators and of Connection to Support See Dwgs. E-1182, E-1183, E-1184.



Suspension Disconnecting Switch Assembly for 66000 V. Substation Bus Wiring.

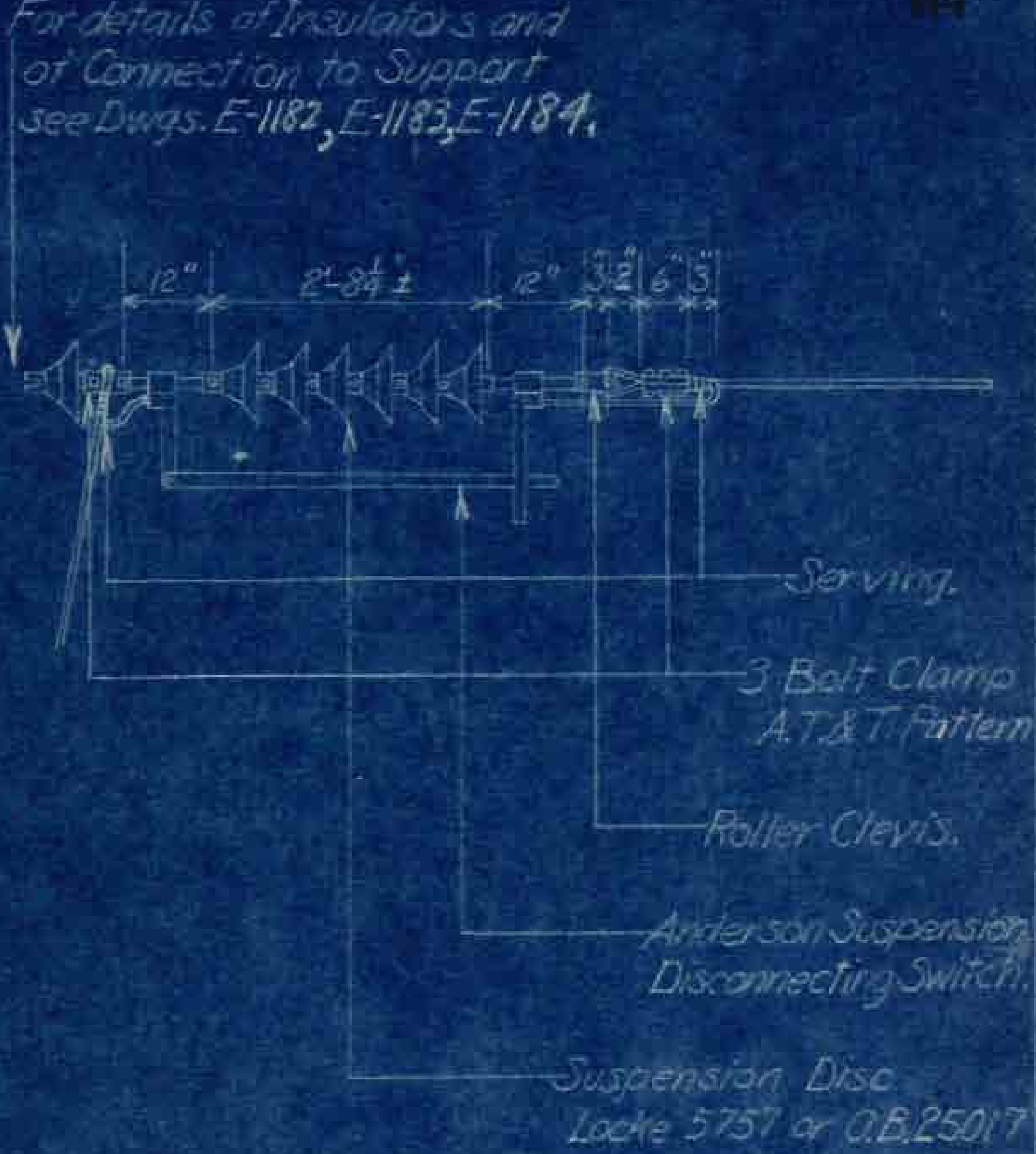
Notes:

1. For 110,000 Volt installations use 7 discs.

STANDARD BUS WIRING
SHEET NO. 14

SCALE $\frac{1}{2}$"=12" DATE: [illegible]-23
OUTDOOR SUBSTATIONS.
I.H. LOVETT.

E-1185-1



Suspension Disconnecting Switch Assembly for 66000 V. Substation Bus Wiring.

Notes:

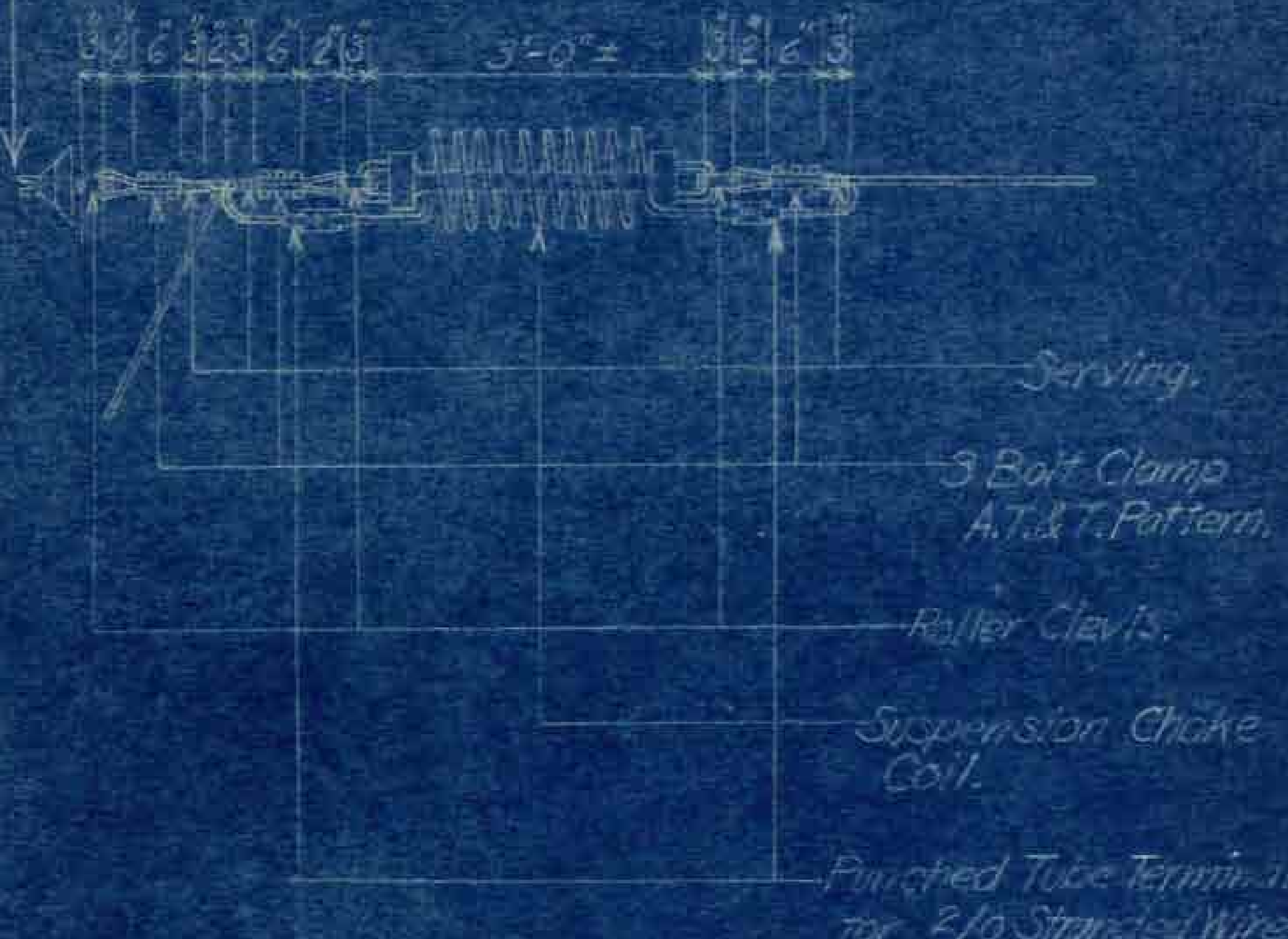
1. For 110,000 Volt installations use 7 discs.

STANDARD BUS WIRING
SHEET NO. 15

SCALE: ½" = 1'-0" DATE: 6-2-23
OUTDOOR SUBSTATIONS
I.H. LOVETT.

E-1186-1

For details of Insulators and of Connection to Support see Dwgs. E-1182, E-1183, E-1184.

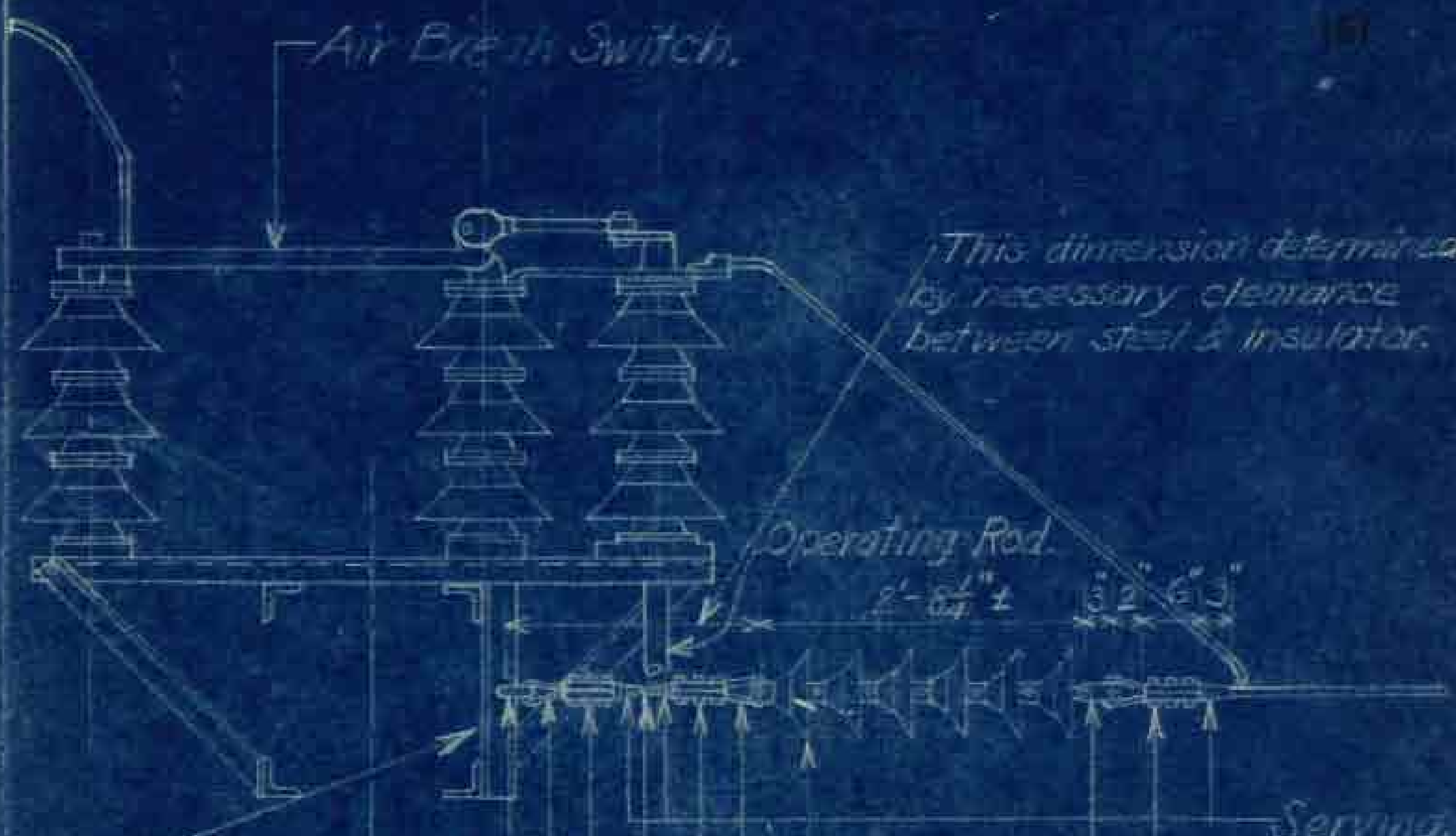


Suspension Choke Coil Assembly for 66000 V. Substation Bus Wiring.

STANDARD BUS WIRING
SHEET NO. 16

SCALE 1"=12" DATE: 3-2-23
OUTDOOR SUBSTATIONS
I.H. LOVETT.

E-1187-1



Air Break Switch Assembly for 66000 V. Substation Bus Wiring.

Notes:

1. For 110 000 volt installations use 7 discs.

STANDARD BUS WIRING
SHEET NO. 17

SCALE ½" = 1'-0" DATE: 3-2-23
OUTDOOR SUBSTATIONS
I. H. LOVETT.

E-1188-1

3. Standardization of Small Capacity Substations.

It has been previously stated that standard substations of small capacity are possible, similarly as standard detail parts are possible. In the standard substation, the arrangement of the equipment should be such as to fit a variety of conditions due to the fact that the conditions are likely to be different in each installation. Some companies have developed standard substations for various capacities and voltages, but the benefits of these developments are reduced when they must be much modified in order to fulfill local conditions.

4. Standard Substation Designs.

A few forms of standard substations are given in the following sheets. These designs are for various voltages from 13,200 to 44,000 for the high tension side. In most cases, the low tension side could be arranged for any voltage used in practice. These small capacity substations are the type that are used for customers' substations; consequently, they have the single circuit, single bus arrangement. They may be located at the ends of feeders from a power station or from a large capacity substation with higher voltage on the high tension side.

While complete standardization of the large capacity substation is generally impossible, it frequently may be standardized to a considerable extent as, for example, the entire low tension bus structure and feeder circuits may be practically identical with that of similar substations. Generally, standard designs are not made for these structures; the designer, being familiar with past practice, makes a design for a new structure as nearly identical with past practice as possible, at the same time fulfilling local requirements. Most of these local conditions and requirements, however, can frequently be fulfilled by varied arrangements in the high tension part of the substation.

In the following designs of small capacity outdoor substations, most of the material and equipment which is specified is that of a standard manufacturer of outdoor substation equipment — the Delta Star Electric Company. On these design sheets is given a single line wiring diagram showing the electrical connections of the substation. On some sheets is given the maximum dimension of transformers thus fixing the maximum capacity of the substation for the given arrangement.

Sheet No. 1 shows the standard substation design which can be adapted for either 13200, 22000 or 33000 volts. The supporting structure is wooden. The equipment consists of: high speed sphere gap lightning arrester; air-break switch with operating handle; horn gap fuse; choke coil; transformers; low tension bus.

Sheet No. 2 shows design which can be adapted for either 13200, 22000, or 33000 volts. The supporting structure is wooden. The equipment consists of: aluminum cell lightning arrester connected to line through disconnecting switch; air-break switch with operating handle; Schweitzer and Conrad fuse; choke coil; transformers; and low tension bus.

Sheet No. 3 shows design for 13200, 22000, or 33000 volts, with wooden structure. Equipment consists of: air-break switch with operating handle; horn gap fuse and high speed sphere gap lightning arrester; Schweitzer and Conrad fuse; choke coil; transformers; and low tension bus.

Sheet No. 4 shows design for 13200, 22000, or 33000 volts, with wooden structure. Equipment consists of: air-break switch with operating handle; horn gap lightning arrester connected to line through a horn gap fuse; Schweitzer and Conrad fuse; choke coil; transformers; low tension bus.

Sheet No. 5 shows design which is practically identical with that of Sheet No. 2 except that the structure is steel instead of wood.

Sheet No. 6 shows design which is practically identical with that of Sheet No. 3 except that the structure is steel instead of wood.

Sheet No. 7 shows design of a substation of

3000 kv-a. capacity, and 22000 volts, with a steel structure. The equipment is arranged for a location at the end of a circuit and consists of: high speed sphere gap lightning arrester connected to line through disconnecting switch; air-break switch and operating handle; choke coil; Schweitzer and Conrad fuse; transformers; low tension bus; low tension disconnecting switch.

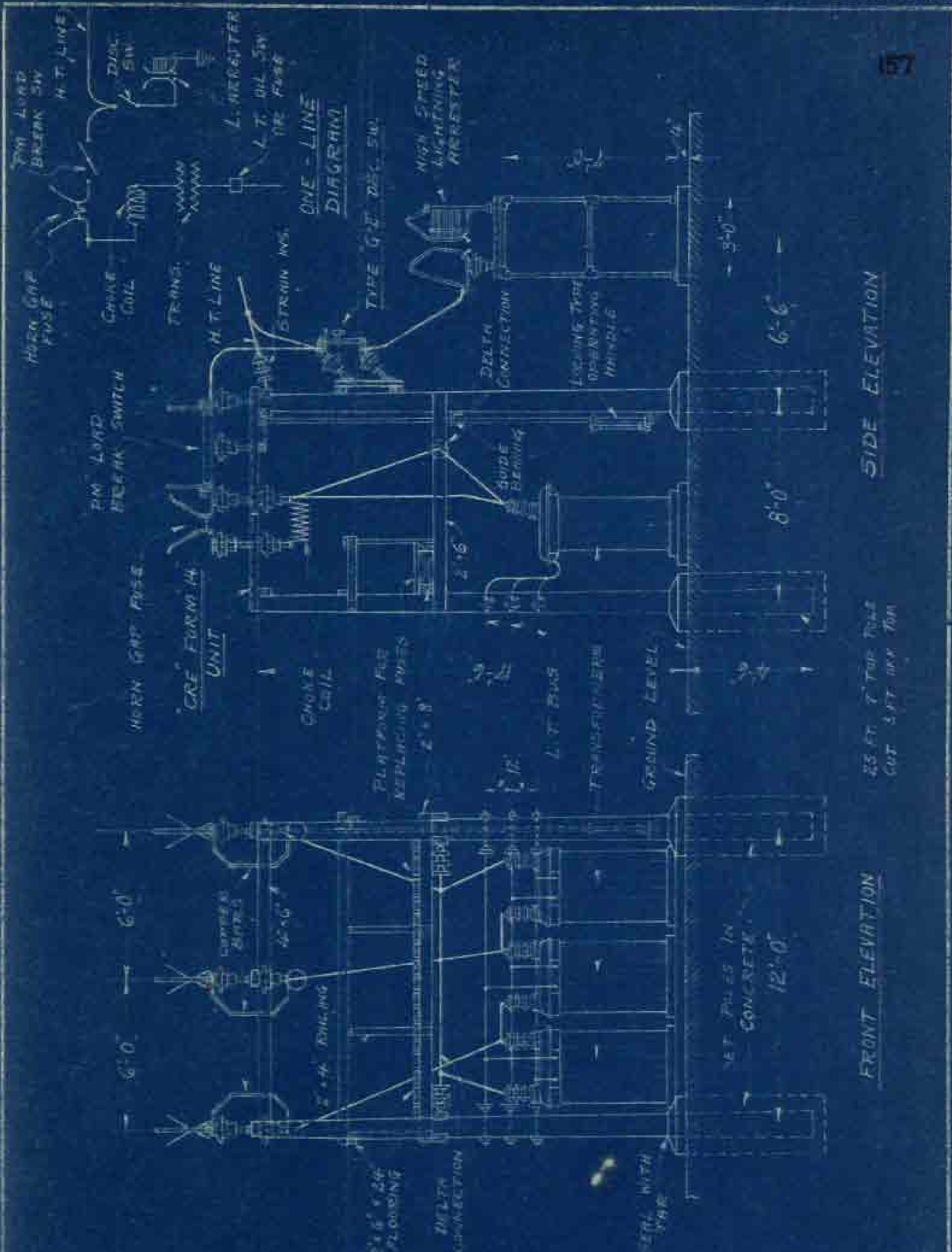
Sheet No. 8 shows design of substation of 3000 kv-a. capacity, 33000 volts, steel structure, and equipment similar to that of Sheet No. 7. The arrangement, however, is different in that this substation is connected to a circuit that passes through the station instead of ending at the station, as in design of Sheet No. 7. Two air-break switches are arranged to permit the tap to the substation to be connected to either the incoming or the outgoing line or to both lines in which case the line would be continuous.

Sheet No. 9 shows design of a substation of 600 kv-a. capacity, 33000 volts, with a steel structure. The equipment consists of: oxide film lightning arrester connected to line through type G-3 General Electric Company fuse; choke coil; air-break switch and operating handle; Schweitzer and Conrad fuse; metering outfit; transformers; and low tension bus.

The foregoing designs merely illustrate possible arrangements of equipment to fulfil certain conditions.

Other designs can be based upon these, taking into account the different conditions and requirements in regard to capacity, voltage, type and amount of equipment, and the desired arrangement of connections.

157



Sheet No. 1

C. [illegible]

APPROVED: [illegible]

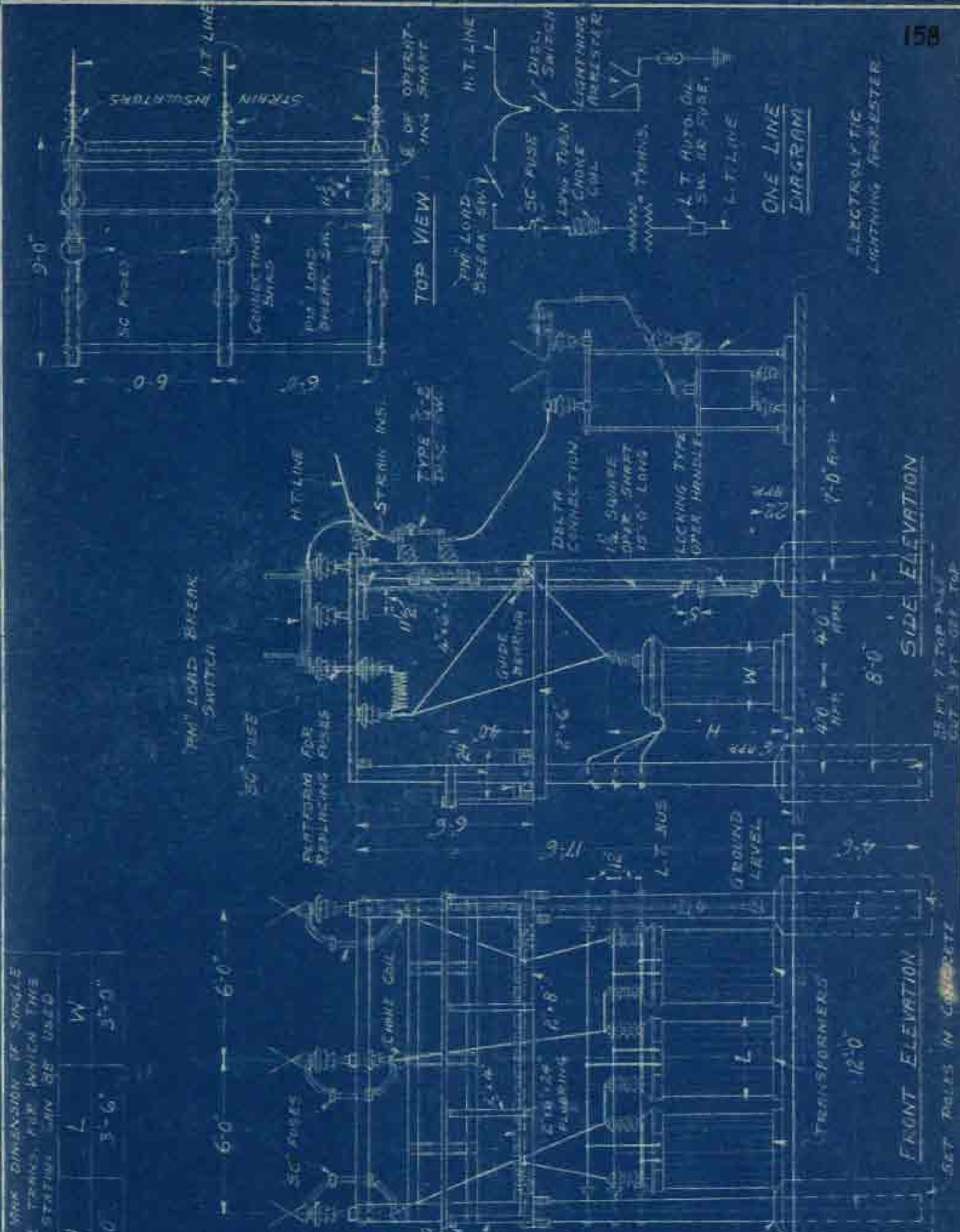
TYPE "RL" FORM 32 SUB - STATION
FOR VOLTAGES UP TO & INCLUDING 33000 V.

FIRST MADE FOR: STANDARD EQUIPMENT

11256

DATE: 7-1-18

PRINTS TO FILE: E-1, [illegible], D-3 M-



Sheet No. 2

C.

APPROVED:

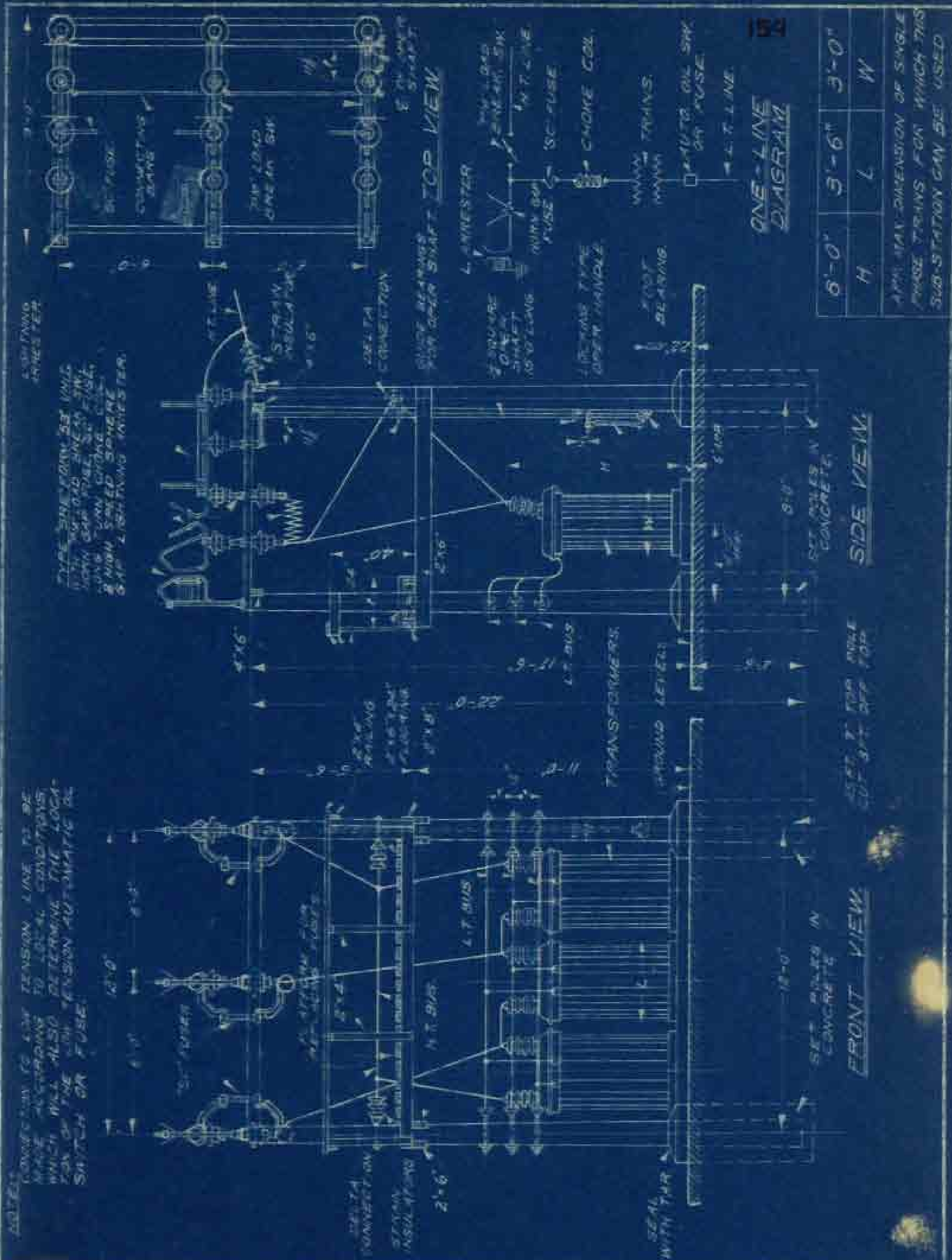
TYPE 'AL' FORM 33 SUB-STATION
FOR VOLTAGES UP TO & INCLUDING 33000 V.
FOR KVA CAP. OF TRANS. SEE TABLE

FIRST MADE FOR: DOMINION GLASS CO. LIMITED MONTREAL, CANADA.

11264

DATE: 8-19-18

154



Sheet No. 3

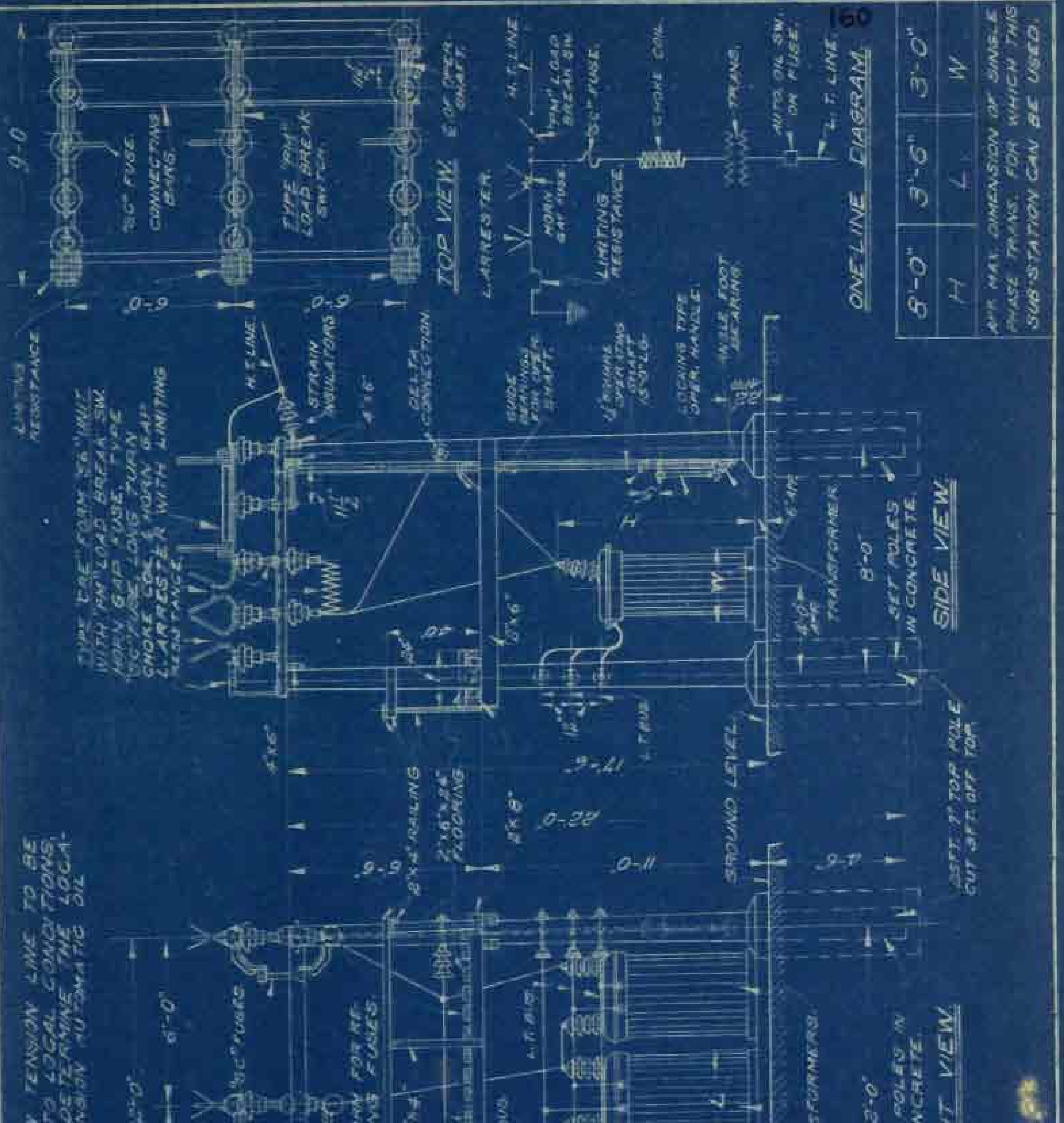
TYPE "AL" FORM "3D" SUB-STATION FOR VOLTAGES UP TO AND INCLUDING 33000 VOLTS.
FOR MAX CAP OF TRANS. SEE TABLE.
FIRST MADE FOR: STANDARD.

11332

DATE: 6-17-1919

PRINTS TO FILE: E-1, D4, 00, N-1, D-6

160



TYPE "AL" FORM "SIC" SUB-STATION FOR VOLTAGES UP TO & INCLUDING 33000 VOLTS.

FOR MAX. CAP. OF TRANSFORMERS SEE TABLE

FIRST MADE FOR: STANDARD

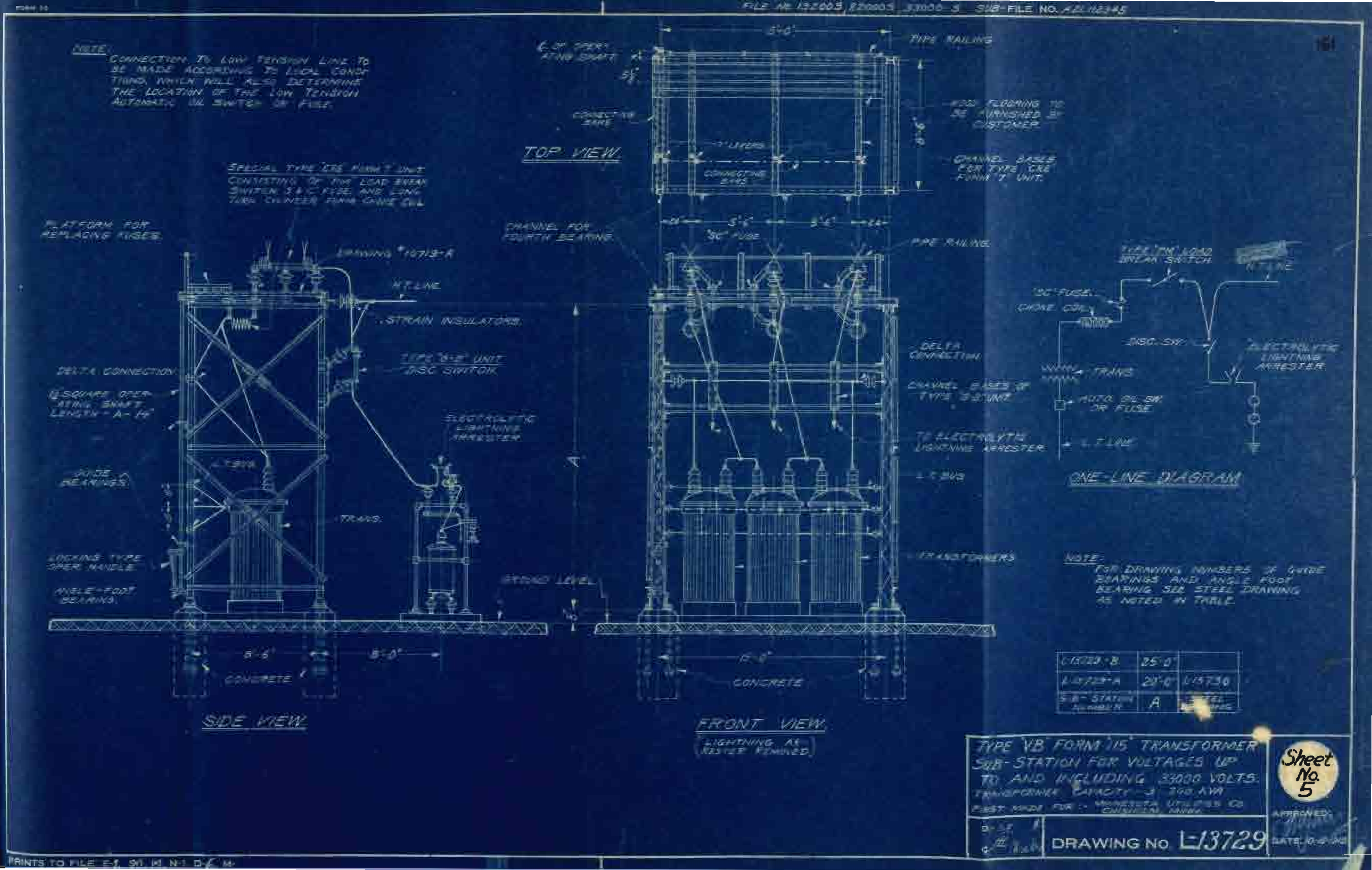
APPROVED:

11320

DATE: 4-18-1919.

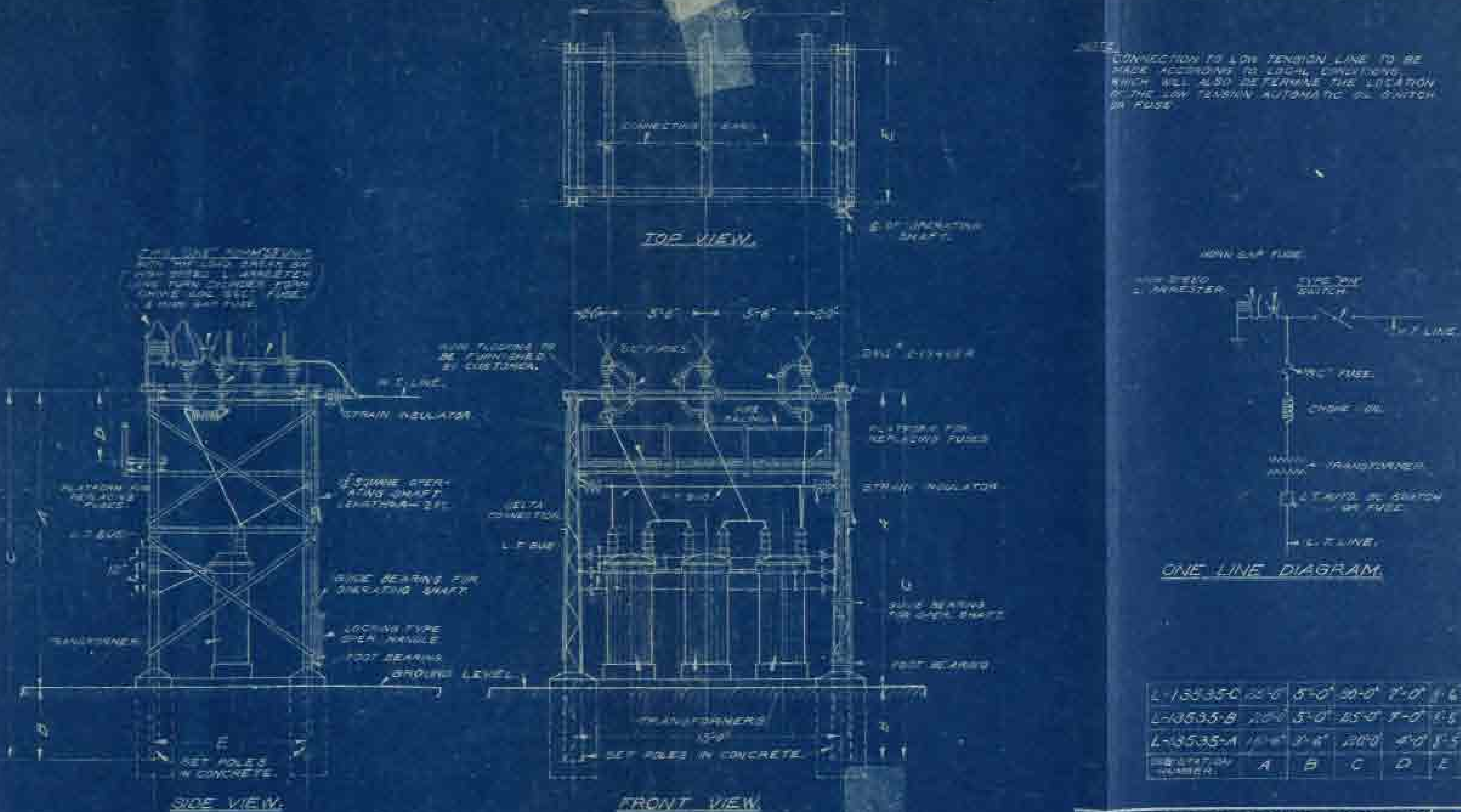
Sheet No. 4

PRINTS TO FILES: E-1, ..., N-1, D-10, ...



FILE No 132003, 220005, 33000-S SUB-FILE No. A2L112345
NOTE:
CONNECTION TO LOW TENSION LINE TO BE MADE ACCORDING TO LOCAL CONDITIONS, WHICH WILL ALSO DETERMINE THE LOCATION OF THE LOW TENSION AUTOMATIC OIL SWITCH OR FUSE.
TOP VIEW
PIPE RAILING
WOOD FLOORING TO BE FURNISHED BY CUSTOMER.
CHANNEL BASES FOR TYPE "CRE" FORM "T" UNIT.
CONNECTING BARS
SPECIAL TYPE "CRE" FORM "T" UNIT CONSISTING OF THE LOAD BREAK SWITCH, S & C FUSE, AND LONG TUBE CYLINDER FORM CHOKE COIL.
PLATFORM FOR REPLACING FUSES.
CHANNEL FOR FOURTH BEARING.
"SC" FUSE
H.T. LINE.
STRAIN INSULATORS.
TYPE "S-2" UNIT DISC SWITCH.
DELTA CONNECTION
ELECTROLYTIC LIGHTNING ARRESTER.
GUIDE BEARINGS.
TRANS.
LOCKING TYPE OPER. HANDLE.
ANGLE-FOOT BEARING.
GROUND LEVEL.
CHANNEL BASES OF TYPE "S-2" UNIT.
TO ELECTROLYTIC LIGHTNING ARRESTER.
L.T. BUS
TRANSFORMERS
CONCRETE
SIDE VIEW
FRONT VIEW
(LIGHTNING ARRESTER REMOVED)
TYPE "PM" LOAD BREAK SWITCH
H.T. LINE
"SC" FUSE.
CHOKE COIL
DISC. SW.
ELECTROLYTIC LIGHTNING ARRESTER.
TRANS.
AUTO. OIL SW. OR FUSE.
L.T. LINE
ONE-LINE DIAGRAM
NOTE:
FOR DRAWING NUMBERS OF GUIDE BEARINGS AND ANGLE FOOT BEARING SEE STEEL DRAWING AS NOTED IN TABLE.
L-13729-B 25'-0"
L-13729-A 20'-0" L-13730
SUB-STATION NUMBER A STEEL DRAWING
TYPE "VB" FORM "115" TRANSFORMER SUB-STATION FOR VOLTAGES UP TO AND INCLUDING 33000 VOLTS.
Sheet No. 5
APPROVED:
DRAWING No L-13729
PRINTS TO FILE

NOTE.
CONNECTION TO LOW TENSION LINE TO BE MADE ACCORDING TO LOCAL CONDITIONS, WHICH WILL ALSO DETERMINE THE LOCATION OF THE LOW TENSION AUTOMATIC OIL SWITCH OR FUSE.



L-13535-C	22'-6"	5'-0"	30'-0"	7'-0"	8'-6"	
L-13535-B	20'-0"	5'-0"	25'-0"	7'-0"	8'-5	L-13577
L-13535-A	16'-6"	3'-6"	20'-0"	4'-0"	8'-5	
SUB-STATION NUMBER	A	B	C	D	E	STEEL DWG. No.

NOTE.
FOR DRAWING NUMBERS OF GUIDE BEARINGS, FOOT BEARING, AND BASES OF "RW" SWITCH SEE STEEL DRAWING AS NOTED IN TABLE.

TYPE "VB" FORM "74" TRANSFORMER SUB-STATION FOR VOLTAGES UP TO AND INCLUDING 33000 VOLTS TRANS. CAP. 3-200 K.V.A.
FIRST MADE FOR: STANDARD.

Sheet No. 6

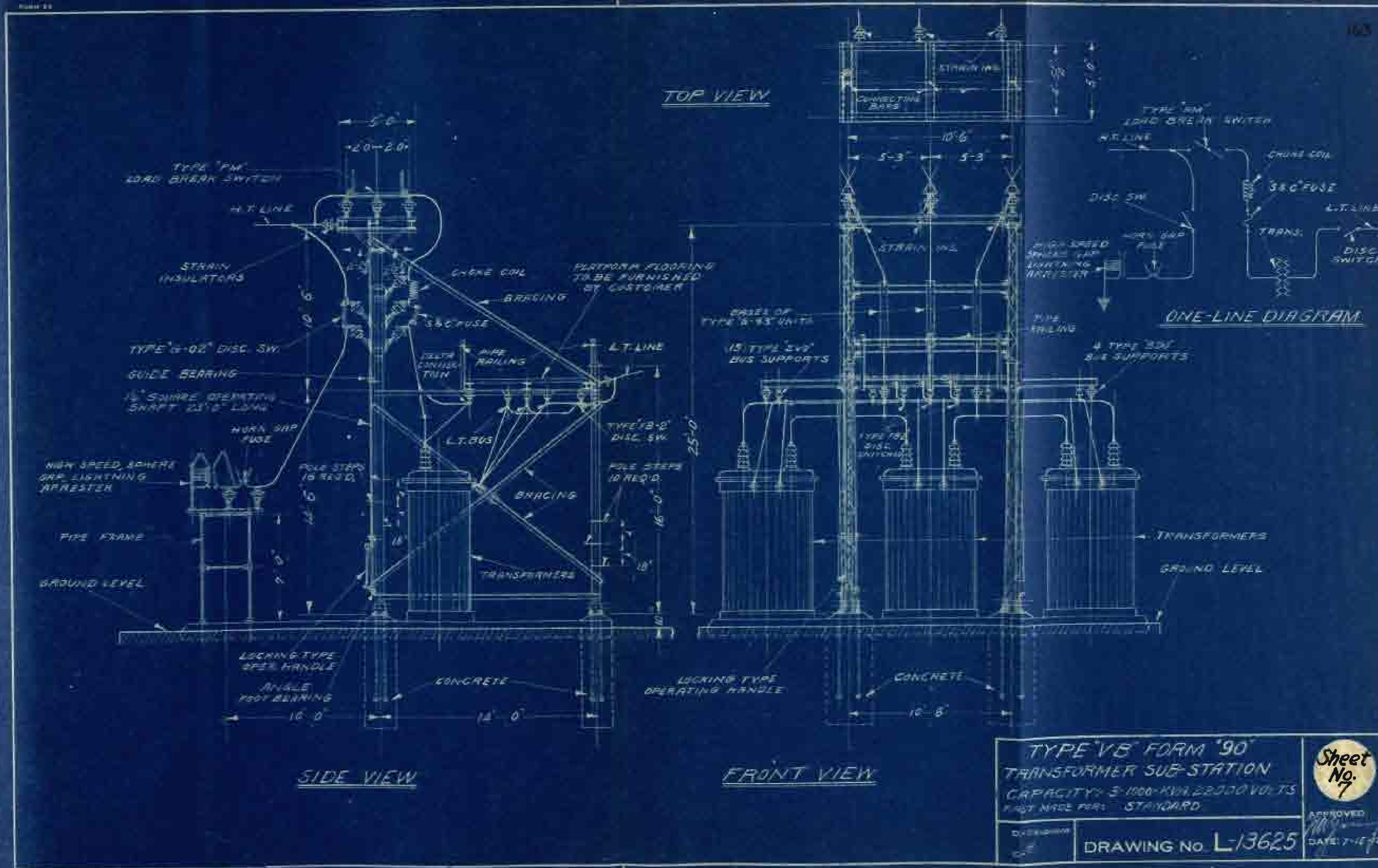
APPROVED

DRAWING No. L-13535

DATE: 2-15-1919

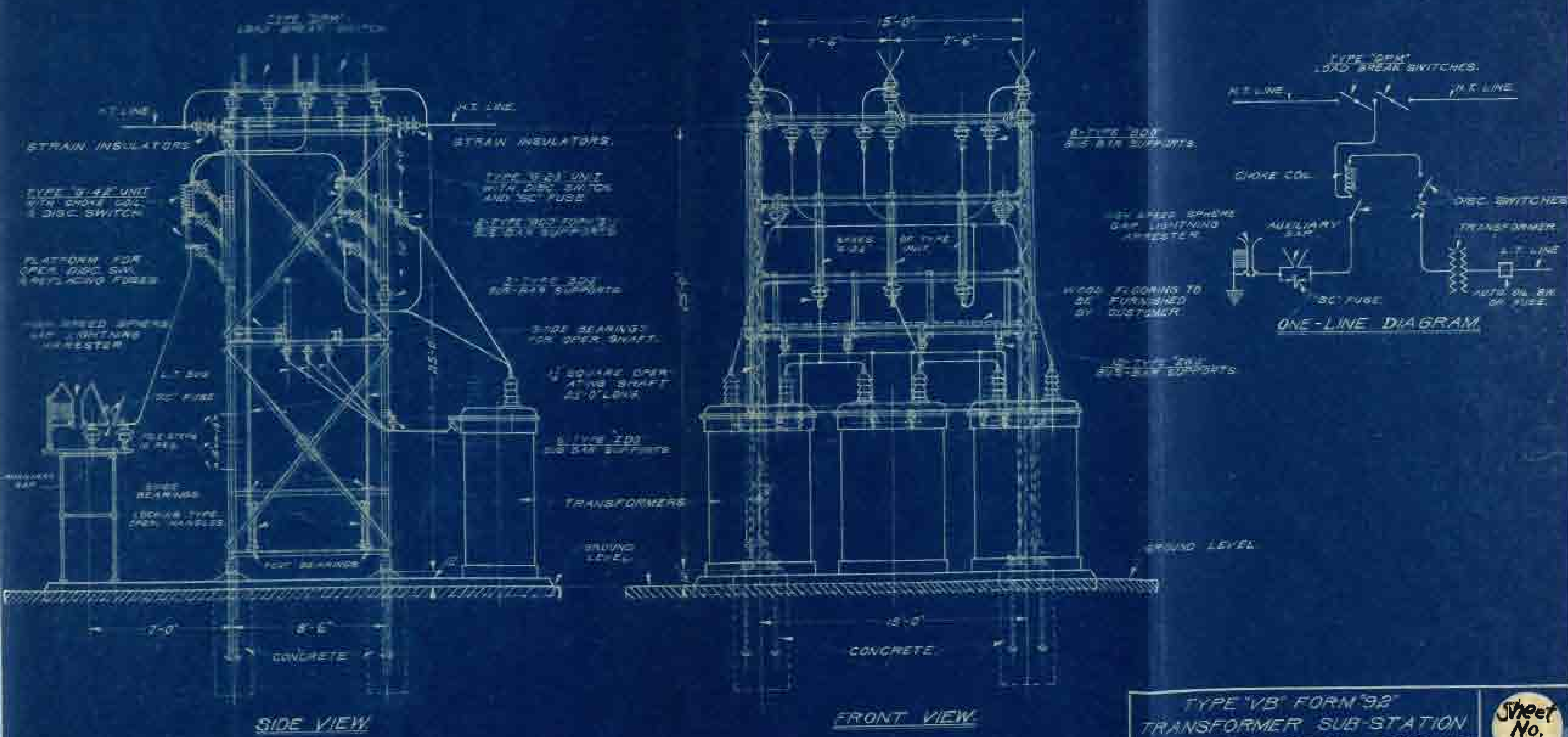
REVISED 5. 14. 19.

PRINTS TO FILE: E.S. SQ. N. N.Y. D.S. M.



FILE NO. 22000-S
SUB-FILE NO. A21.112345
163
TOP VIEW
STRAIN INS.
CONNECTING BARS
10'-6"
5'-3"
5'-3"
TYPE "PM" LOAD BREAK SWITCH
H.T. LINE
STRAIN INSULATORS
CHOKE COIL
BRACING
S&C FUSE
TYPE "G-02" DISC. SW.
GUIDE BEARING
1½" SQUARE OPERATING SHAFT 25'-0" LONG
HORN GAP FUSE
HIGH SPEED SPHERE GAP LIGHTNING ARRESTER
PIPE FRAME
GROUND LEVEL
PLATFORM FLOORING TO BE FURNISHED BY CUSTOMER
PIPE RAILING
L.T. LINE
L.T. BUS
TYPE "B-2" DISC. SW.
POLE STEPS 16 REQ'D.
POLE STEPS 10 REQ'D.
BRACING
TRANSFORMERS
LOCKING TYPE OPER. HANDLE
ANGLE FOOT BEARING
CONCRETE
16'-0"
14'-0"
25'-0"
16'-0"
10'-6"
SIDE VIEW
BASES OF TYPE "G-93" UNITS
15 TYPE "SVS" BUS SUPPORTS
STRAIN INS.
PIPE RAILING
4 TYPE "SVS" BUS SUPPORTS
TRANSFORMERS
GROUND LEVEL
LOCKING TYPE OPERATING HANDLE
CONCRETE
10'-6"
FRONT VIEW
TYPE "AM" LOAD BREAK SWITCH
H.T. LINE
CHOKE COIL
S&C FUSE
DISC SW.
L.T. LINE
HIGH SPEED SPHERE GAP LIGHTNING ARRESTER
HORN GAP FUSE
TRANS.
DISC SWITCH
ONE-LINE DIAGRAM
TYPE "VB" FORM "90"
TRANSFORMER SUB-STATION
CAPACITY:- 3-1000-KVA 22000 VOLTS
FIRST MADE FOR: STANDARD
Sheet No. 7
APPROVED
DRAWING No. L-13625

FILE NO. 33000-S- SUB-FILE NO. A21.112345



TYPE "VB" FORM "92"
TRANSFORMER SUB-STATION
TRANS. CAP. 3-1000 K.V.A. - 33000 VOLTS
FIRST MADE FOR: LOUISVILLE GAS & ELECTRIC CO. LOUISVILLE, KY.

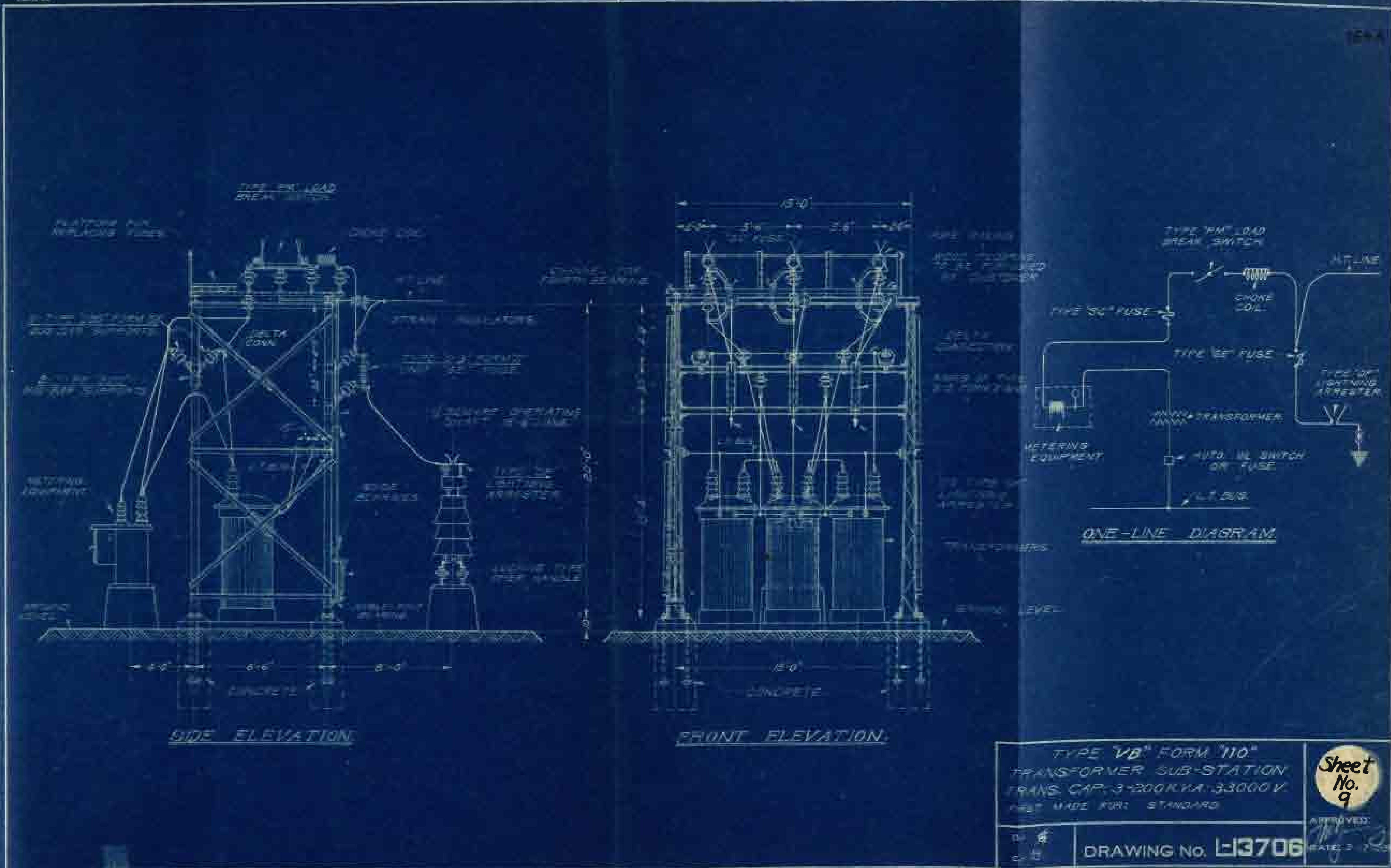
Sheet No. 8

APPROVED:

DRAWING No. L-13632

DATE 1-24-15

PRINTS TO FILE


FILE NO. 33000-S- SUB-FILE NO.
TYPE "FM" LOAD BREAK SWITCH
CHOKE COIL
H.T. LINE
STRAIN INSULATORS
DELTA CONN.
METERING EQUIPMENT
GROUND LEVEL
CONCRETE
SIDE ELEVATION
15'-0"
20'-0"
FRONT ELEVATION
TRANSFORMERS
TYPE "SC" FUSE
CHOKE COIL
TYPE "SE" FUSE
TYPE "OF" LIGHTNING ARRESTER
TRANSFORMER
METERING EQUIPMENT
AUTO. OIL SWITCH OR FUSE
L.T. BUS
ONE-LINE DIAGRAM
TYPE "VB" FORM "110"
TRANSFORMER SUB-STATION
TRANS. CAP. 3-200 K.V.A. 33000 V.
FIRST MADE FOR: STANDARD
DRAWING No. L-13706
Sheet No. 9
APPROVED:
DATE:
PRINTS TO FILE

XI. OUTDOOR SUBSTATIONS OF THE NEW ENGLAND POWER COMPANY

1. Description of the New England Power System.

The New England Power Company System is the result of the growth and combination of several smaller power systems, the most important of which were the Connecticut River Power Company and the Connecticut River Power Transmission Company. Through stock ownership in a holding company, called the New England Company, other power systems are closely associated with the New England Power System. The most important of these other power systems are: the Connecticut River Power Company of New Hampshire, the Bellows Falls Power Company, and the Rhode Island Power Transmission Company.

In addition to these systems, which are operated as a unit, the New England Power Company system is connected to a large number of other systems, some of which are associated through ownership of stock of both companies by the same person or persons. Other connected systems are not associated except by mutual contract.

An examination of the diagram of the lines of the New England Power System, on page 200 , will show the interconnected lines as well as the lines of the New England Power System. Some of the most important of these connected lines are: the line to the power system of the Fall River Electric Company, connected near Providence; the line to the power system at New London, connected near Providence; the line to the Eastern Connecticut Power Company at Norwich, connected at Webster; the line connecting with the Rockville and Willimantic Lighting Company from Palmer; the Turners Falls Power and Electric Company system, connected at Leverett; the Adirondack Power and Light Company, connected at Adams Substation; the Colonial Light and Power Company, connected at Charlestown; and the Edison Electric Illuminating Company of Boston, connected at Wachusett. The lines shown in red are the high tension lines of the New England Power System. The low tension lines at 22000 volts and 13800 volts are not shown. The central line from Readsboro, Vermont, across most of the State of Massachusetts to Millbury, is operated at 110,000 volts. This line is 76 miles long, is supported on 580 steel towers by insulators with 8 and 9 units. The conductors are 4/0 seven-strand copper. A double circuit 66000-volt line connects power stations No. 2, No. 3, No. 4, No. 5, and Searsburg with the central operating point at Millbury. A similar line connects the power station at Vernon with the substations at Fitchburg, Gardner, Leominster, Clinton, Worcester and Millbury. From Millbury a similar line extends to the thermo-electric station and substation at Uxbridge, and to substations at Woonsocket, Pawtucket, and Providence (Rhode Island), where connection is made with the Narragansett Electric Lighting Company.

The New England Power System diagram shows that the system is arranged according to the loop or ring plan. When a failure or short-circuit develops on any section of the line, that section can be cut out of service without interrupting service on the remainder of the system. This, however, may require a change in the direction of the flow of energy in some parts of the system. For the control of the oil circuit breakers- which cut out faulty sections of the line - balanced power, and overload relays are used on the double circuits. On double circuits between important substations, balanced power, and overload relays are used on both ends of each circuit. The overload relays take care of faults on both lines of a double circuit and of troubles due to sustained short circuits caused by failure of other relays to function properly; they are given a low current and a long time setting. On double circuit lines between generating stations, one end of each circuit is protected by straight overload relays, while the other end is protected by balanced power and overload relays. The determination of the time settings of these relays was an extremely difficult problem requiring a study of short circuit current values for all probable conditions and locations of short circuits. Because each addition to the system required a repetition of these studies and a revision of time settings, a short circuit calculating table was constructed representing the entire power system in miniature. By means of this table, short circuit currents could be determined experimentally. In this power system, where high tension short circuits with characteristics equivalent to over 800,000 kv-a. may develop, the design and arrangement of the switching and protective equipment presents a formidable problem.

2. Substations of the New England Power Company.

In addition to the main substations as indicated on the diagram of the New England Power System, there are a large number of customers' substations of small or medium capacity. Many of these substations are of the outdoor type and were designed by the writer but their description will be omitted in preference to substations of the more important type. Reduced photostats of original drawings, and enlarged photographs of seven of the more important substations of the New England Power Company system are included in this thesis.

a. Millbury Substation.

The original installation of the Millbury Substation was the first large outdoor substation built in New England, and was the first attempt to operate large water-cooled transformers, exposed to the severe New England climate. This original installation, which is shown on page 202, was not designed by the writer; however, he had a part in the designs for the later additions and in the remodeling of the substation.

This substation is located 60 miles from Station No. 2, and is the operating center of the power system. Because of many additions and revisions, little of the original equipment remains. The 66000-volt double circuit line, from the group of power stations on the Deerfield River, and a similar circuit from Vernon Station via Fitchburg, Clinton and Worcester, terminate at this substation. It is also the terminal of the 110000-volt line from the Davis Bridge Station. From Millbury a 66000-volt double circuit line extends to Uxbridge, Woonsocket, Pawtucket and Providence; and another to Webster and Norwich. The switching equipment of the station is arranged for interconnecting and sectionalizing these circuits. The 110000-volt circuit from Davis Bridge Station terminates in auto-transformers which supply the 66000-volt buses and also the 13200-volt feeder buses in the substation. Another tap on these transformers supplies a 4000 kv-a. frequency changer set which is used in supplying energy to the Worcester Consolidated Street Railway at a frequency of 25 cycles. In case of emergency, this frequency changer is inverted, supplying energy from the street railway system to the New England Power Company system.

The frequency changer set is housed in a brick building which also houses the switchboard and provides offices for the system operators. This building formerly housed the 13200-volt feeder equipment, but in 1920 an outdoor feeder bus structure was designed and installed. The detail drawing of this bus structure is shown on page 222 .. Section CC of this drawing shows that the bus structure is of the double bus type, arranged so that any outgoing feed may be connected through the metering outfit and oil circuit breaker to either the main or auxiliary bus by means of the selector disconnecting switches. Also, in case of emergency due to failure of metering outfit or oil circuit breaker, any feeder may be connected directly with the main bus by means of a shunt disconnecting switch. This connection also may be made when repairs or adjustments are necessary on the metering equipment or oil circuit breaker, thus preventing interruption of service to the consumer. Section AA of this drawing shows a similar arrangement of connections for incoming circuits from the transformers to the buses. This section also shows the bus tie oil circuit breaker which connects the two buses together and may be used to take the place of any feeder oil circuit breaker. When this connection is desired, all the other feeders are connected to the auxiliary bus which is energized from the transformers.

The feeder to be arranged for emergency connection is then connected, as previously explained, to the main bus, and the bus tie circuit breaker is connected between the main and auxiliary buses. Section BB shows both an incoming circuit from transformers and an outgoing feeder circuit. On the drawing is given a complete material list for electrical equipment. A photograph of the remodeled substation is shown on page 203 .

b. Woonsocket Substation.

The Woonsocket Substation is located on the double circuit line from Millbury to Providence. On page 210 is given a photostat of a drawing showing the plan view of the general arrangement of equipment. The double circuit line passes through the station and has suspension disconnecting switches in each circuit on both sides of the station. By means of these disconnecting switches either circuit may be opened between this substation and the adjacent substations at Millbury and Pawtucket. In addition to this sectionalizing, the circuits may be cross-connected as, for example, the incoming L12 circuit may be connected to the outgoing K11 circuit, or the incoming

K11 circuit may be connected to the outgoing L12 circuit. This is accomplished by means of the tie bus and the(previously mentioned) disconnecting switches.

This plan view shows the general layout of the transformers and the low tension equipment. One-half the low tension equipment is shown in dotted lines representing a future installation - a plan, commonly followed in designing a substation, for double the capacity needed at the time of the original installation. Two years after the original installation, which was in 1916, this remaining low tension equipment was installed; and in 1920 it was necessary to add another bank of transformers of 9000 kv-a., which was located at the point where the lightning arrester is shown in this drawing. The lightning arresters were then relocated at the ends of the 66000-volt buses, leading to the first two banks of transformers.

A detailed plan of one of the low tension bus structures isshown on page 209. The transformers, feeding this bus structure, have both 13200-volt coils and 22000-volt coils. These coils are connected respectively to 13200 and 22000-volt transformer buses in delta connection. A tap from the 13200-volt transformer bus is then taken around the bus structure, through instrument transformers, oil circuit breaker, and connected to the main 13200-volt bus. This is shown in Section AA on drawing C-539, page 208. A tap from the 22000-volt transformer bus is taken across the substation to the 22000-volt bus structure located on the other side of the yard. The 22000-volt bus structure is practically a duplicate of the 13200-volt bus structure, except that the arrangements are reversed. The 13200-volt coils on the transformers, at the 22000-volt bus structure, feed the main 13200-volt bus; while the 22000-volt coils on the transformers, at the 13200-volt bus structure, feed the main 22000-volt bus. The object of this arrangement is to give increased reliability of service in permitting both main low tension buses to be supplied from one bank of transformers.

Cross Section CC on drawing C-536, page 207, shows how the low tension leads from the transformers are connected to the transformer buses; and also shows how a feeder circuit is connected from the main 13200-volt bus, through the oil circuit breaker, instrument transformers, and disconnecting switch to the outgoing line. Feeders are connected to the 22000-volt bus structure in a similar manner; thus, it is evident that these bus structures are of the single bus type. Because of the operating advantages of the double bus system, these bus structures were re-designed in 1920 for the double bus arrangement, as shown in drawing H-844, page 223. Comparison of the sectional views on this drawing with those of drawings C-536 and C-539 will show the changes that were made. Section AA on drawing H-844 shows the location of the auxiliary bus and the method of connecting an outgoing feeder either to the main or to the auxiliary buses by means of the selector disconnecting switch. This sectional view also shows the shunt disconnecting switch which connects the feeder circuit directly with the auxiliary bus in case of emergency, or for inspection of instrument transformers or of oil circuit breaker. It is not possible to connect the feeder directly to the main bus without connecting it to the auxiliary bus. Emergency connection to either bus was considered unnecessary, due to the remote possibility of simultaneous failure of instrument transformers, oil circuit breaker and auxiliary bus.

Section BB of this drawing, H-844, shows the method of connecting the transformer bus,through metering and switching equipment, either to the main or to the auxiliary buses. Also the shunt disconnecting switch permits transformer circuit to be connected directly to the auxiliary bus in case of emergency. A bus tie oil circuit breaker is installed which may replace any feeder circuit breaker or may tie the two buses together as in the Millbury Substation low tension bus structure.

All transformers are mounted on wheels and on standard gage tracks supported by concrete foundations. The track makes it possible to bring any transformer needing repairs into the building where a hoist is provided for removing the core from the transformer. The building also contains the switchboard, storage battery for operating the oil circuit breakers, motor-generator set for charging storage batteries, oil and water pumps, and a 7500 kv-a. synchronous condenser (not shown in these drawings as it was added at a later date).

Drawing B-48, page 211 , shows sections and elevations of the substation as indicated on drawing H-133. The elevations show how the buses are arranged on different levels in order to give sufficient clearances. On pages 205 and 206, photographs are given which show two views of the substation.

c. Pawtucket Substation.

The next substation on the line from Millbury to Providence is the Pawtucket Substation. The high tension lines do not pass through this substation as at Woonsocket; a short tap from the lines leads into this station and terminates there. Also this substation differs from that at Woonsocket in that the low tension metering and switching equipment is located indoors. However, the general arrangement of the switching equipment is quite similar to that at Woonsocket; consequently, a description will not be given.

The plan view showing the general arrangement of the equipment is given in drawing F-2, page 212. Sectional and elevational views are shown in drawing F-10, page 213. Photographs showing views of the substation are given on pages 214, 215, and 216.

This substation was designed before that at Woonsocket and was formerly the terminal of the line from Millbury. This accounts for the difference in design. The substation operates at 66000 to 22000 and

13200 volts and has capacity of 30,000 kv-a.

d. Providence Substation.

The Providence Substation provides a means for an exchange of energy between the New England Power Company and the Narragansett Electric Lighting Company. It is located adjacent to the thermo-electric power station of the latter company at tide water.

The complete layout of this substation is shown on drawing H-369, page 224. The 60-foot towers supporting the incoming 66000-volt lines are necessary in order to provide sufficient clearance of these lines over nearby buildings. After passing through disconnecting switches and oil circuit breakers, the incoming high tension lines terminate on 66000-volt buses on the 22-foot level to which the oxide film lightning arresters are connected. At right angles to these buses, on the 34-foot level, are the buses leading to the transformers. A circuit breaker is connected in one of these buses leading to the transformers, serving as a bus tie switch. The connections are arranged so that either incoming circuit may be connected to either or both transformer buses. Sectionalizing air-break switches are installed in these transformer buses, permitting these connections. Similar air-break switches connect each transformer to the transformer buses, permitting any transformer to be taken out of service. All load on a transformer must be removed by disconnecting the low tension oil circuit breaker located in the station switch house. The air-break switch, which can interrupt only a small current, can then be opened breaking the magnetizing current of the transformer. The low tension leads from the transformers pass through disconnecting switches and underground cables to oil circuit breakers in the power station and thence to the 11000 volt buses. The transformers are of the three-phase water cooled type, 5000 kv-a. each. The station is designed for 10 transformers, or a capacity of 50,000 kv-a. Reference is made on this drawing to other drawings of standard parts of substations as, for example, foundations for equipment, and details of bus wiring, choke coil, and insulator assembly. A material list giving the electrical equipment is also included.

e. Adams Substation.

The plan view showing the general arrangement of equipment at the Adams Substation, formerly called the Zylonite Substation, is given on page 217 . The substation is arranged for six high tension 66000-volt circuits- two incoming and outgoing circuits (or two circuits passing through the station), and two other outgoing circuits. A study of the plan view and also of the view of sections and elevations given on drawing C-526, page 218 , will show how either of the two main high tension circuits may be sectionalized, or how one circuit on one side of the substation may be opened and the other circuit on the other side of the substation may be opened, and the remaining circuits may be cross connected. Thus, for example, with failure of No. 10 Line to No. 5 Station, and No. 9 Line to Zylonite Steam Plant, the disconnecting switches would be opened, sectionalizing these circuits. Then, with both high tension oil circuit breakers closed, No. 9 Line to No. 5 Station would be connected to No. 10 Line to Zylonite Steam Plant, and at the same time the 66000-volt transformer buses in the substation would be energized. This sectionalization, or cross-connection, of high tension lines can also be made when a transformer in the substation fails. In this event, the Burke air-break switches would be opened, disconnecting the transformers from the transformer bus.

This substation is similar to that at Pawtucket in that the low tension equipment is in the building, with the exception of the lightning arresters. Double low tension buses are provided to either of which the transformer circuits can be connected, and from either of which energy may be supplied through instrument transformers and oil circuit breakers to outgoing 22000-volt feeders. The building contains, in addition to the low tension equipment, the switchboard, oil and water pumps, transformer core lifting hoist, storage battery for operating oil circuit breakers, and motor generator set for charging storage batteries. The substation is designed for a capacity of 12000 kv-a.

f. Worcester Substation.

The part of the Worcester Substation which was designed by the writer is the low tension 13200-volt bus structure, two photographs of which are given on pages 219 and 220. This bus structure is of the double bus type, arranged so that a transformer circuit may be connected through instrument transformers and oil circuit breakers to either of the buses. In case of failure of any of this equipment, the transformer circuit may be connected directly with one of the buses by means of a shunt disconnecting switch. The bus tie oil circuit breaker may then be used to connect this bus to the other bus to which the feeder circuits are connected. The bus tie circuit breaker may thus take the place of the transformer circuit oil circuit breaker. In a similar way, any one of the feeder circuits may be connected directly to the auxiliary bus by means of the shunt disconnecting switch. Then the bus tie circuit breaker may be used to connect the auxiliary bus to the main bus, which would be the bus to which the transformer circuit would be connected. Obviously, the bus tie circuit breaker can replace only one transformer circuit oil circuit breaker or one feeder circuit oil circuit breaker at one time. More extensive provisions for maintaining service in case of emergency were not considered necessary.

g. Vernon Switching Station.

The Vernon Switching Station is an example of the large capacity outdoor station used in connection with a power station. This use of the outdoor station has been previously described. A cross-sectional view of the power station, designed in 1920, is shown on drawing R-434, page 225. Leads from the alternators are connected through the low tension oil circuit breakers to the low tension double bus. From these buses, leads are connected through similar oil circuit breakers to the low tension side of the transformers, located on the floor above. The leads from the high tension side of the transformers are connected through the high tension oil circuit breakers and through selector disconnecting switches to either the main or auxiliary high tension buses. These two high tension buses are then extended beyond the end of the station (shown in photograph on page 221) to the outdoor switching station, the details of which are shown in drawings H-599, and H-600, pages 226 and 227.

In sections FF and GG of drawing H-599 the leads from the power station auxiliary and main buses are shown entering the switching station. These sections also show the main and auxiliary buses of the switching station and the means of connecting the power station buses to these buses. In the same bay with the leads from the power station auxiliary bus, the 66000-volt Keene line is connected through disconnecting switches and oil circuit breaker to selector disconnecting switches which permit the line to be connected either to the main or to the auxiliary bus. An indoor type of oil circuit breaker, formerly located inside the power station, was used in this circuit and protected by a steel frame house covered with corrugated steel and asbestos board. The leads enter and leave house through standard wall bushings. In the right hand part of section GG is shown the provision for a future line to Keene; at present it is being used for a bus tie oil circuit breaker, the uses being similar to those described for bus tie circuit breakers in other substations.

The cross-sectional view of the remaining two bays of the station is shown in section EE, drawing H-600. In these bays are connected, on one side, the double circuit 66000-volt lines to Worcester and to Shelburne Falls. The connections are arranged in a similar manner as for the Keene line: from selector disconnecting switches permitting connection to either 66000-volt bus, through oil circuit breakers, and disconnecting switches. The 80-foot towers, supporting the Worcester lines, are necessary in order to provide sufficient clearance of conductor over the Connecticut River, in a span of 1500 feet. The potential transformers shown connected to the Shelburne Falls lines are for the purpose of synchronizing between this power station and that at Shelburne Falls. Lightning arresters, shown in elevation DD, are connected to both the main and to the auxiliary buses.

A material list on drawing H-600 gives all the electrical equipment of the station and item numbers show the location of the equipment. Also, a list of reference drawings is given in connection with the conduit plan for the station, the steel structure design, and the foundation plan.

h. Conclusion.

The outdoor substations which have been described in the preceeding pages have been selected as representatives of the usual types of this kind of installation. To summarize briefly, the types may be classified as follows:

(1). The outdoor substation in which practically all equipment is of the outdoor type, with the switchboard and some auxiliary equipment in a building, as at the Millbury and the Woonsocket Substations.

(2). The outdoor substation in which the high tension equipment is of the outdoor type, with the low tension equipment in a building, as at the Pawtucket and the Adams Substations.

(3). The outdoor substation in which most of the high tension equipment is in a building and the low tension equipment of the outdoor type, as in the Worcester Substation.

(4). The outdoor station used in connection with a power station, with transformers and high tension buses outdoors, as at the Providence Substation.

(5). The outdoor station used in connection with a power station as a high tension switching station with transformers located indoors, as at Vernon Outdoor Switching Station.

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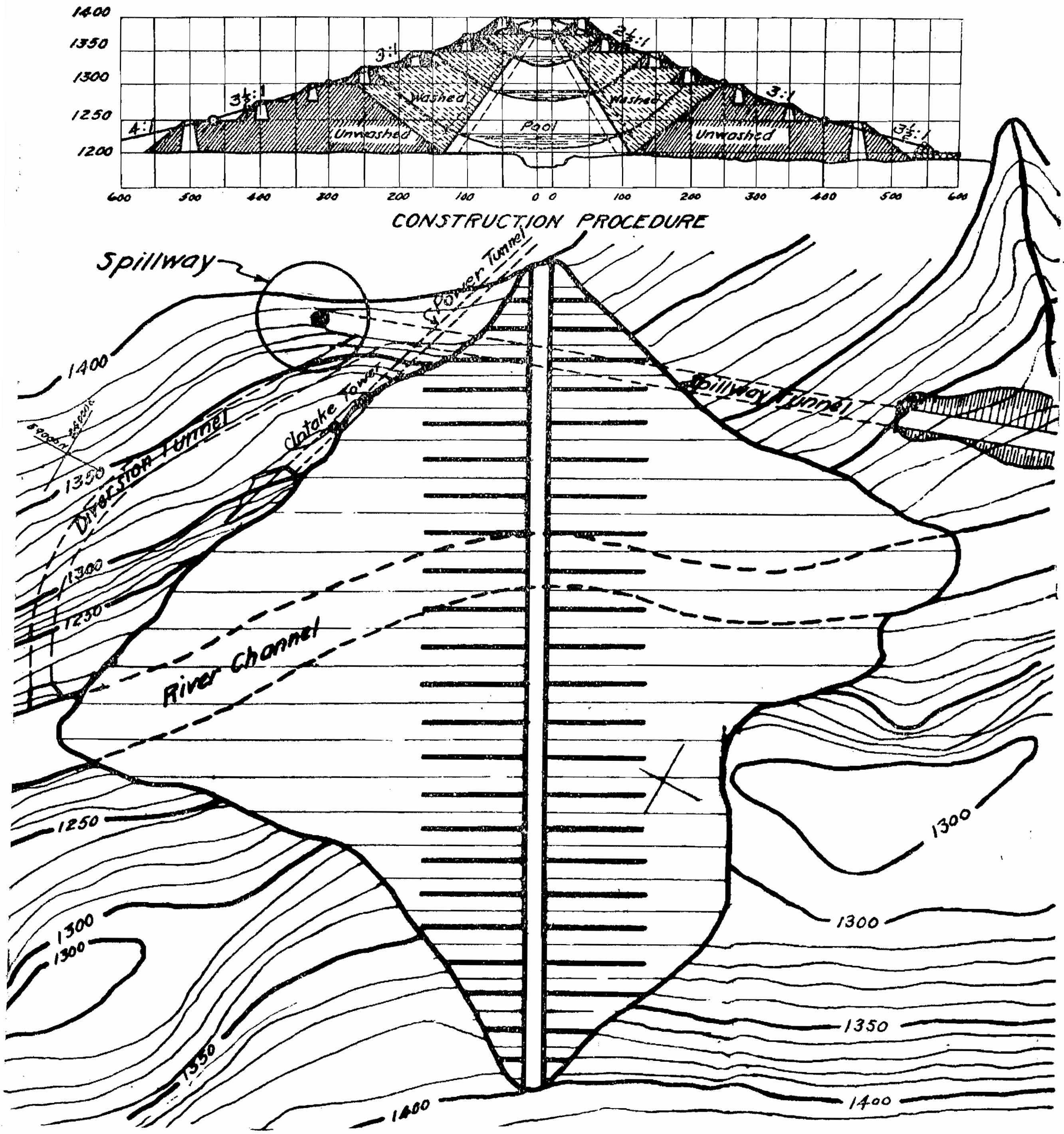
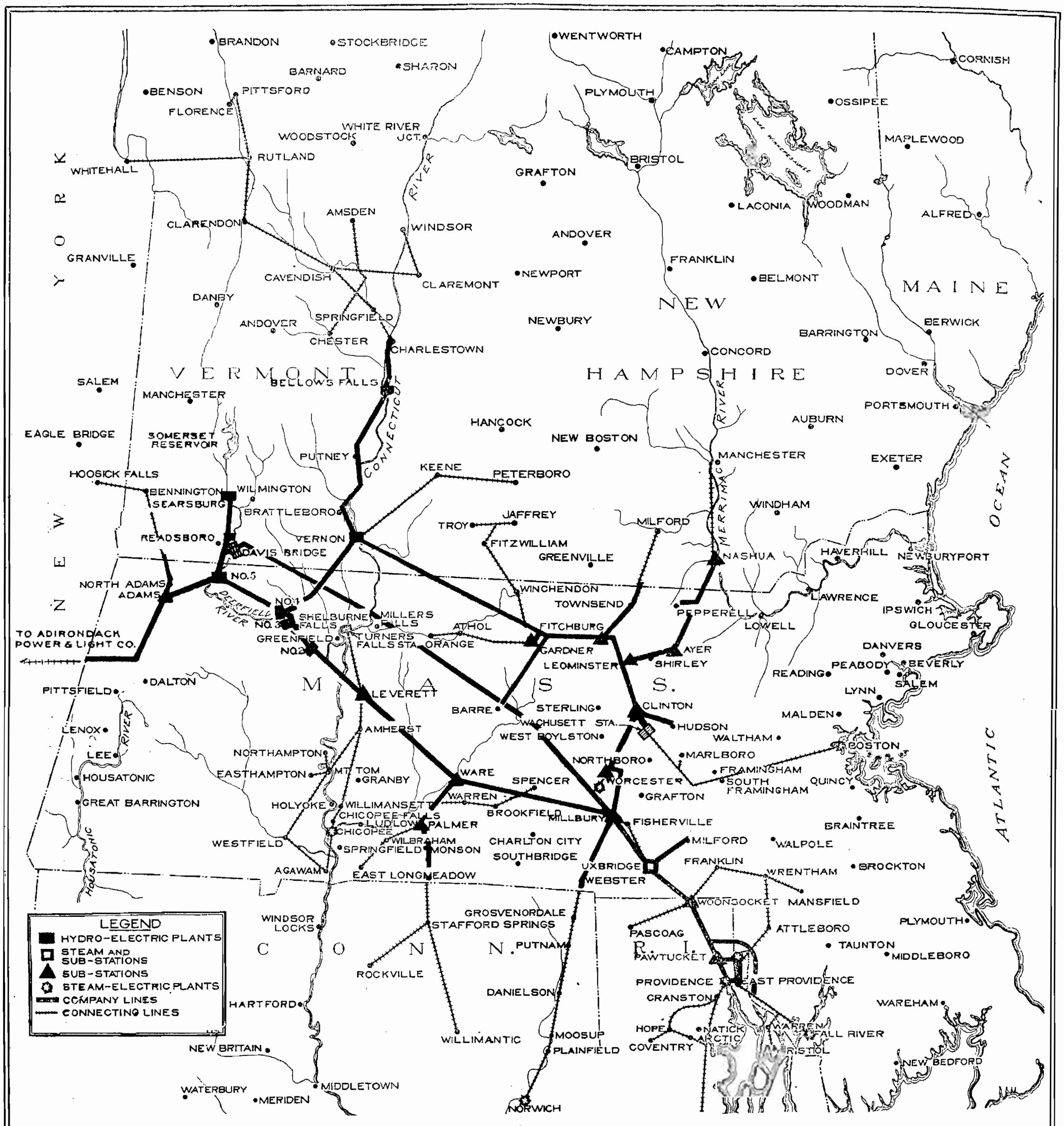
NEW ENGLAND POWER SYSTEM

DAVIS BRIDGE PROJECT

THE HIGHEST EARTH DAM IN THE WORLD





LINES OF THE

NEW ENGLAND POWER SYSTEM

AND CONNECTING LINES

FACTS OF INTEREST

DAM

This dam is the highest earth dam in the world built by the modified hydraulic fill method. The size, and the speed with which it is being constructed, makes it one of the most interesting construction jobs under way at the present time. The first earth was placed in June 1922 and the dam will be completed December 1, 1923. Cold weather prevented work from January 1 to April 15, 1923.

Height	200 ft.	Volume in Dam	1,900,000 cu. yds.
Width of Base	1300 ft.	Area covered by Dam	18 acres
Width of Crest	25 ft.	Number of Steam Shovels	8
Length of Crest	1250 ft.	Number of Standard Gauge Locomotives	15
Elevation of Crest above sea level	1525 ft.	Number of large Dump Cars	102
Drainage Area (below Somerset)	154 sq. mi.		

DIVERSION TUNNEL

The diversion tunnel was constructed large enough to carry any probable flood during the construction of the dam. It was started February 1, 1922, and completed September 15, 1922. It is lined with concrete throughout.

Length	1500 ft.	Capacity	20,000 cubic feet per second
Diameter	22½ ft.		

SPILLWAY

The spillway is unique in design, being circular in shape and resembling an inverted phonograph horn, or morning glory blossom. Water discharged over the edge of this spillway will drop vertically 180 feet and discharge through the lower end of the diversion tunnel, which will be plugged near the upper end upon completion of the dam.

Diameter at top	160 ft.	Capacity	30,000 cu. ft. per sec.
Diameter at throat	22½ ft.	Rock excavation	30,000 cu. yds.
Spillway length	500 ft.	Concrete	5,000 cu. yds.
Elevation below top of dam	14 ft.		

RESERVOIR

The reservoir formed by the big dam will be 10 miles long and will cover an area of 3½ square miles. Railroad, highways, schools and cemeteries have been relocated, and the area cleared of buildings and all growth.

Railroad relocated	8 miles	Area flooded	2200 acres
Work started	December 1922	Woodland	800 acres
Work completed	December 1923	Pasture and meadow	1400 acres
Highways discontinued	14 miles	Length	10 miles
New highways	4 miles	Capacity	38,000,000,000 gals.
Cemeteries moved	3		5,000,000,000 cu. ft.
Date of filling	March 1924		115,000 acre ft.
Maximum depth	185 ft.	Maximum operating drawdown	90 ft.

PRESSURE TUNNEL

The pressure tunnel runs in a straight line from the dam to the power house. It is located entirely in a mica schist rock and will be lined throughout with concrete. Work was started September 1922. Excavation will be completed in November 1923 and the lining completed by April 1, 1924. Work is carried on from 4 headings, working 2 shifts per 24 hours.

Length	2½ miles	Minimum thickness of lining	6 inches
Diameter	14 feet	Concrete lining	20,000 cu. yds.
Normal Capacity	1,400 cubic feet per second		

SURGE TANK AND PENSTOCKS

The surge tank is of a type known as the Johnson Differential Surge Tank. Inside the main tank is a vertical 8 ft. diameter pipe rising nearly to the top. Because of the 90 foot draw on the reservoir for storage use the tank is of exceptional height.

Height	184 feet
Diameter	34 feet
Plate thickness—maximum	1¼ inches
Rivet diameter—maximum	1½ inches
Weight	450 tons
Penstock weight—each	350 tons
Diameter	9 feet
Plate thickness—maximum	1 inch

POWER HOUSE

The power house is of steel-brick construction with cast stone trimmings. Work was started September 1922 and will be completed December 1923.

Number of units (2 at present)	3
Capacity each unit	20,000 H. P.
Maximum head	390 ft.
Minimum Head	300 ft.
Mean head	350 ft.
Wheel—vertical single runner	360 r. p. m.
Generators—each	16,000 K. V. A.
Generating Voltage	6600 Volts

TRANSMISSION LINE

The new transmission line to handle this new power extends from Readsboro, Vermont to Millbury, Massachusetts, from which point it will be distributed.

Length of line	76 miles
Number of towers	580
Height of towers	50 to 70 feet
Conductors (3 at present)	6 No. 4/0-7 str. copper
Ground wires (1 at present)	2—7/16in. 7 str. cru. steel
Insulators	8 and 9 units
Voltage	110,000 volts
Right of way width	250 feet
Work started	Jan. 1, 1923
To be completed	Mar. 1, 1924
Men employed	200
Construction camps	6

ENGINEERS AND CONTRACTORS

Power Construction Company, Worcester, Mass.

(Subsidiary of the New England Company)

CONSULTING ENGINEERS

J. G. White Engineering Corporation, New York

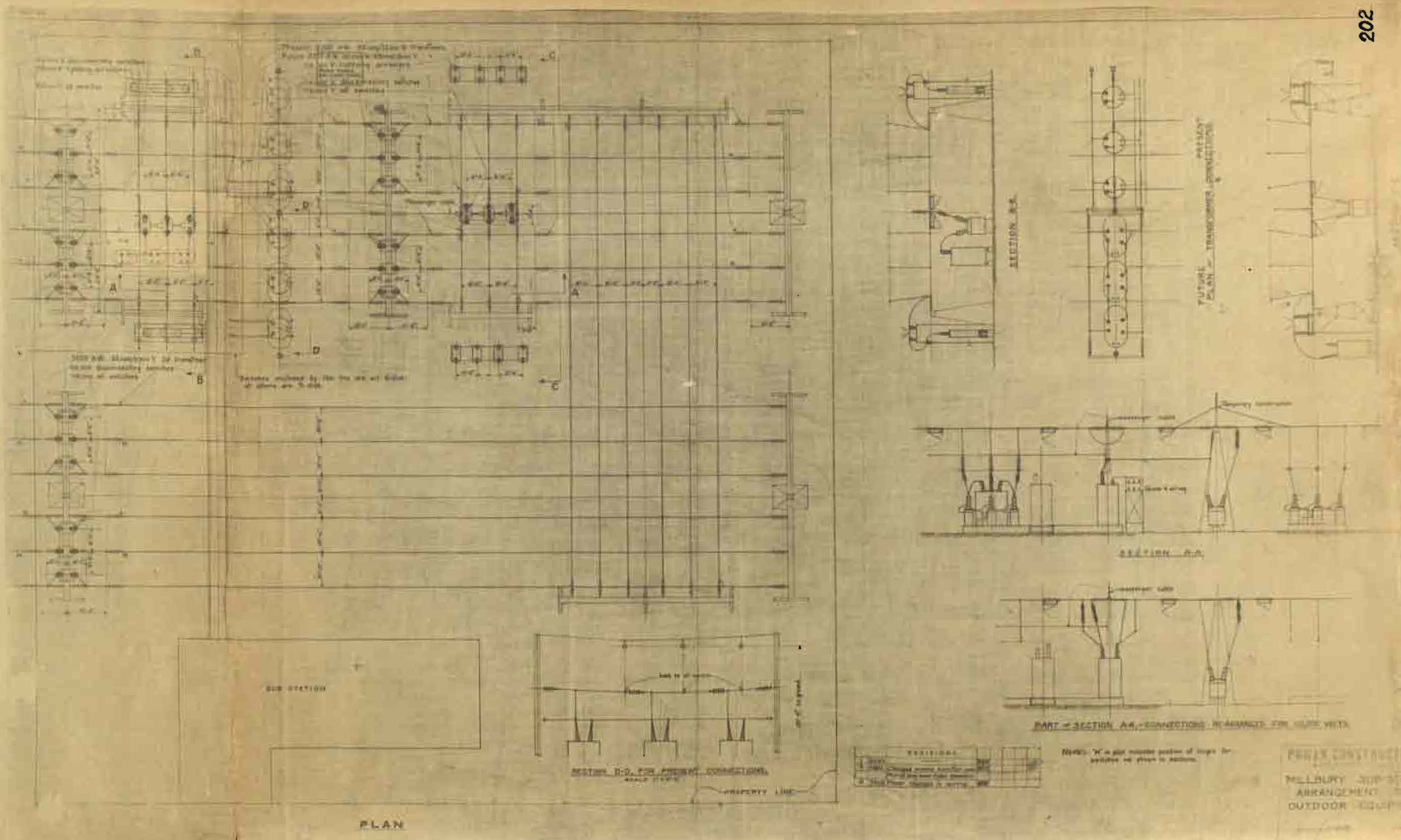
SUB-CONTRACTORS

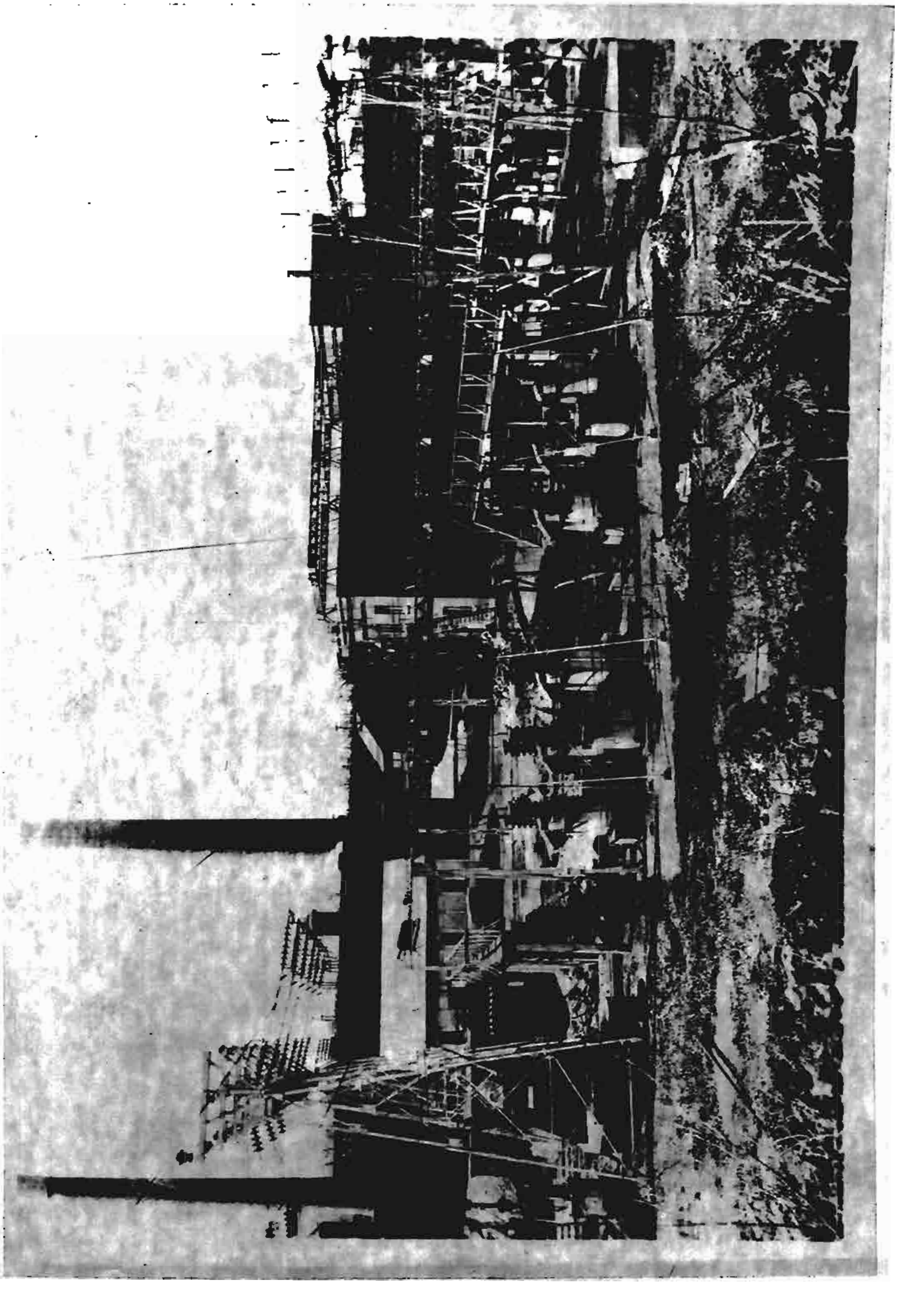
Diversion tunnel and spillway shaft	Rollin Construction Corp., New York
Earth dam	W. F. Carey Co., Inc., New York
Power tunnel	Mason & Hanger Co., Inc., New York
Power house	L. H. Shattuck, Inc., Manchester, N. H.
Surge tank	Riter-Conley Co., Pittsburg
Penstocks	Lancaster Iron Works, Lancaster, Pa.
Turbines	Allis-Chalmers Co., Milwaukee
Electrical equipment	General Electric Co., Schenectady
Transmission line towers	American Bridge Co., New York

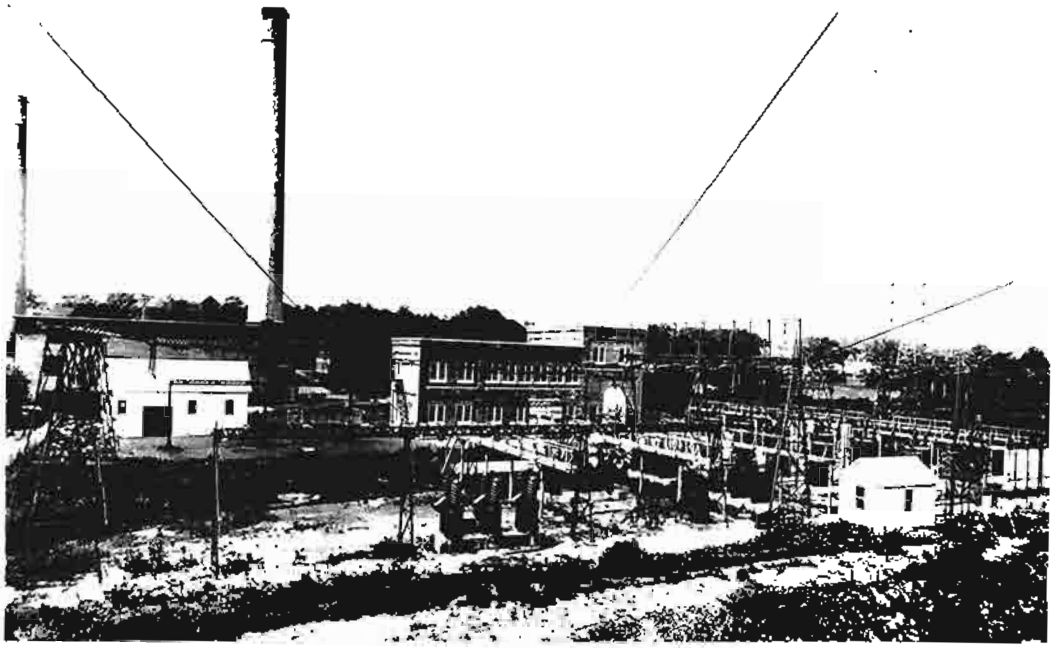
MISCELLANEOUS

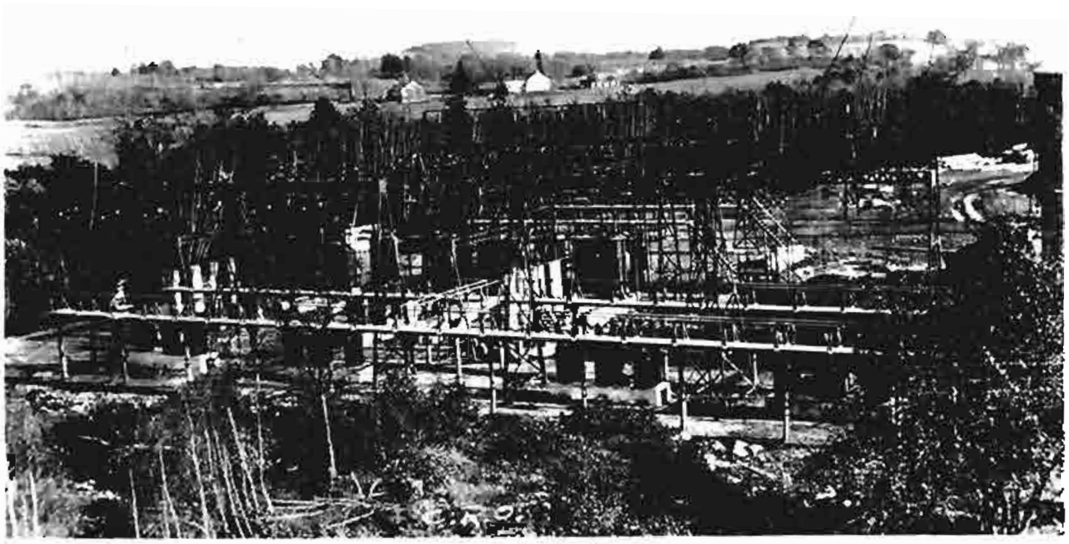
Number of men employed (August 1923)	1,500
Estimated cost including transmission line	$10,000,000

All items of work except those which have been subcontracted are being handled by the Power Construction Company.

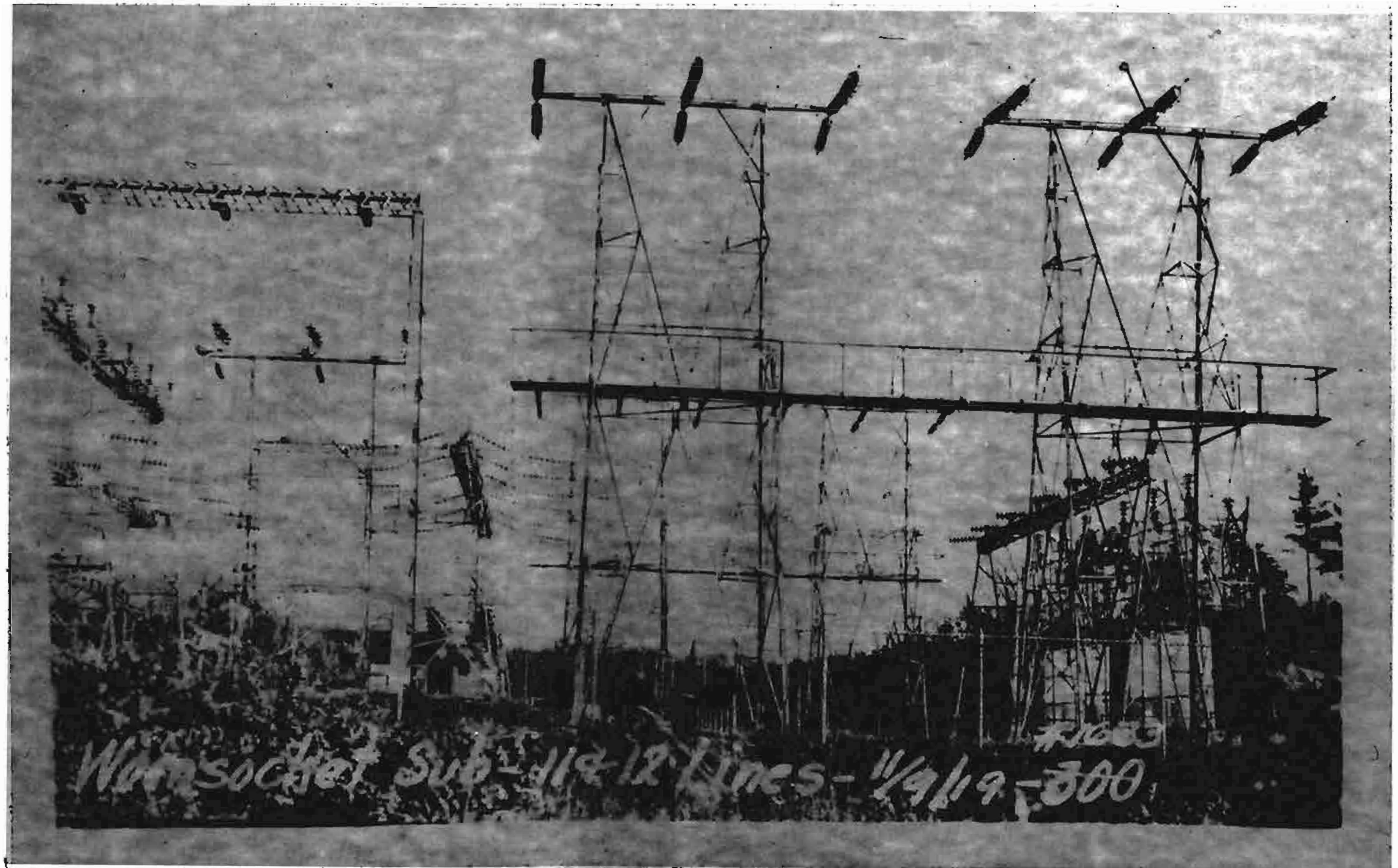

PLAN
SUB STATION
SECTION D-D FOR PRESENT CONNECTIONS
PROPERTY LINE
SECTION B-B
SECTION A-A
FUTURE
PRESENT
PLAN - TRANSFORMER CONNECTIONS
PART - SECTION A-A - CONNECTIONS
REVISIONS
MILLBURY
ARRANGEMENT
OUTDOOR



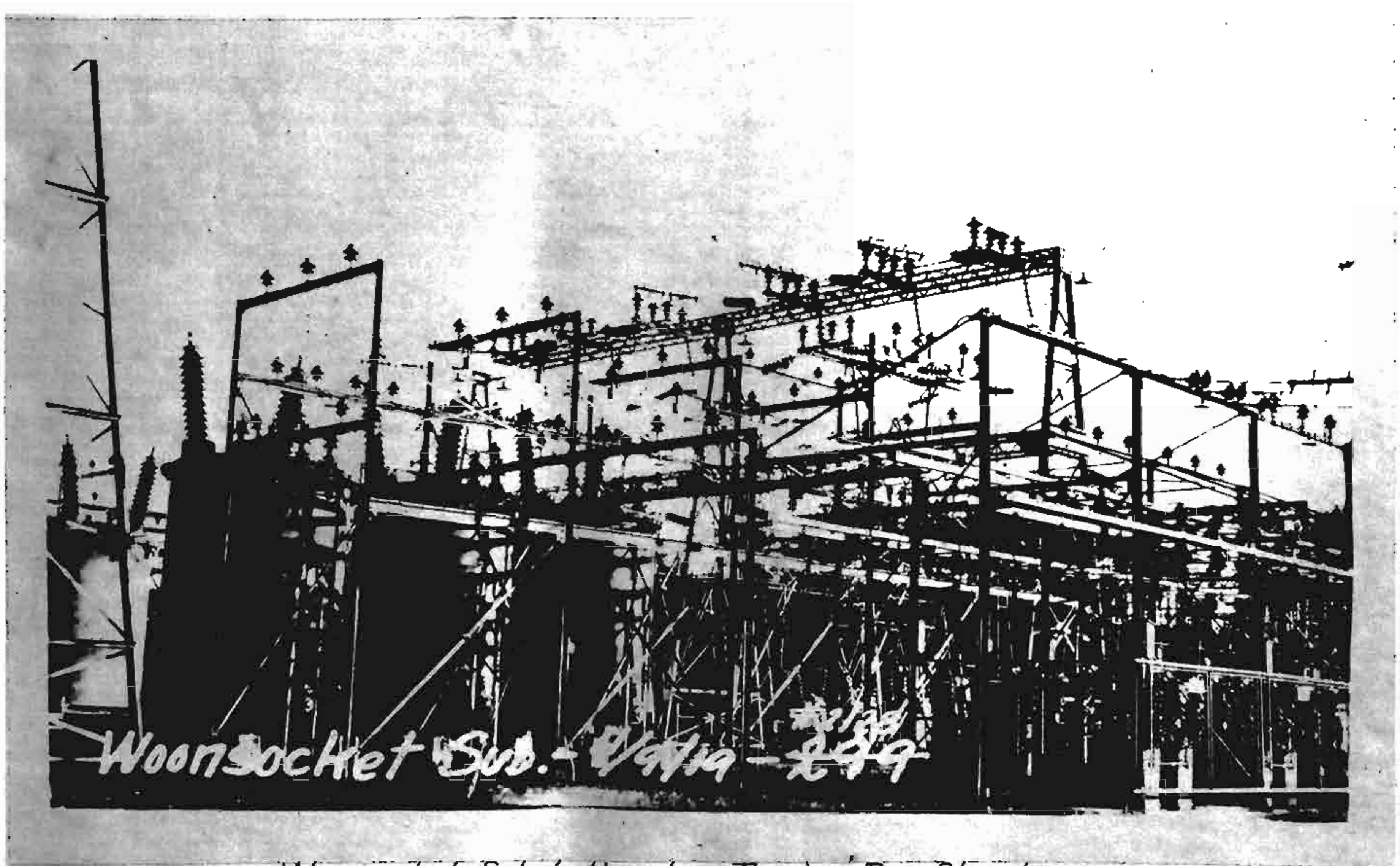




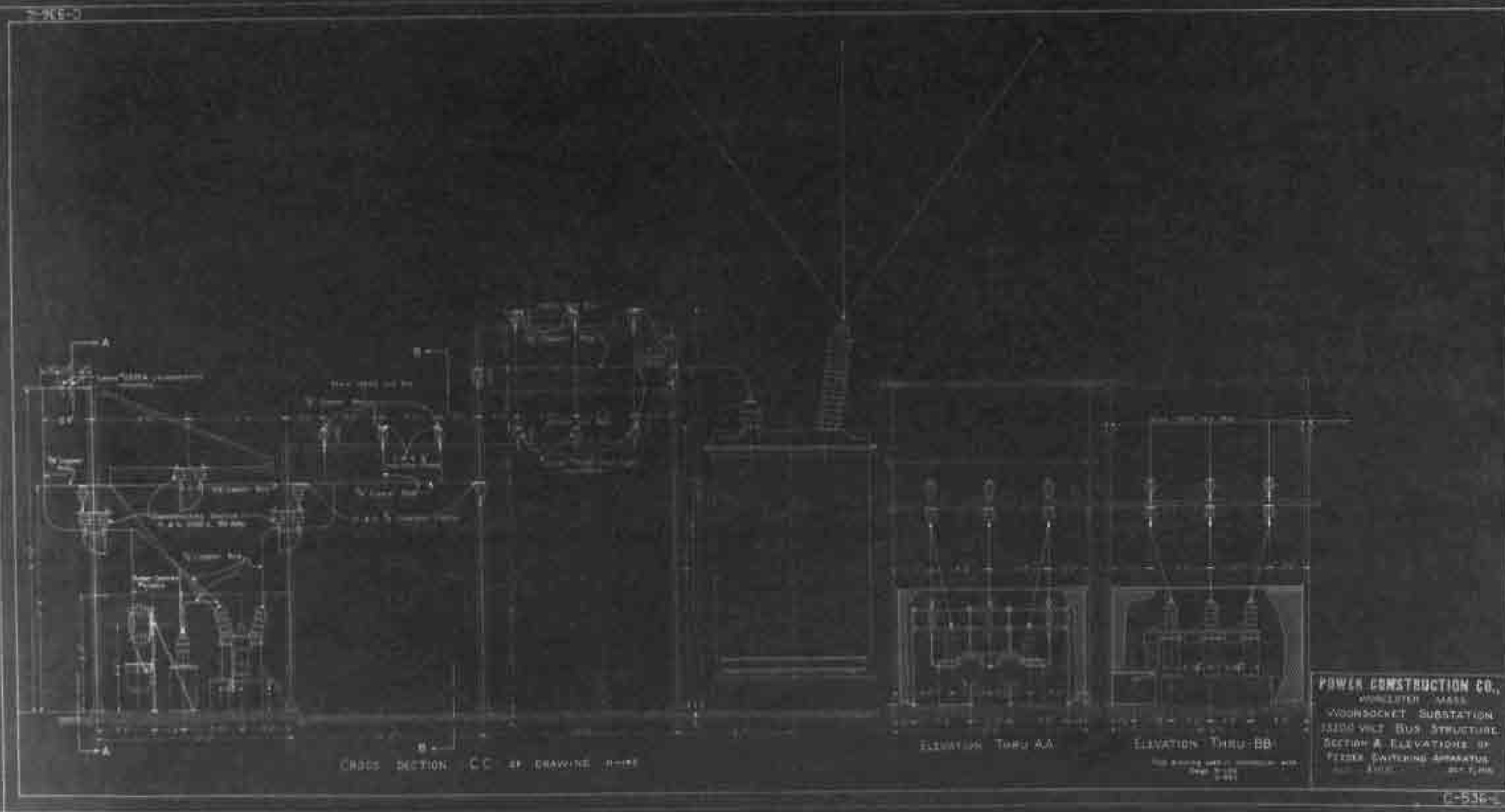
Millbury Substation - High Tension Equipment.



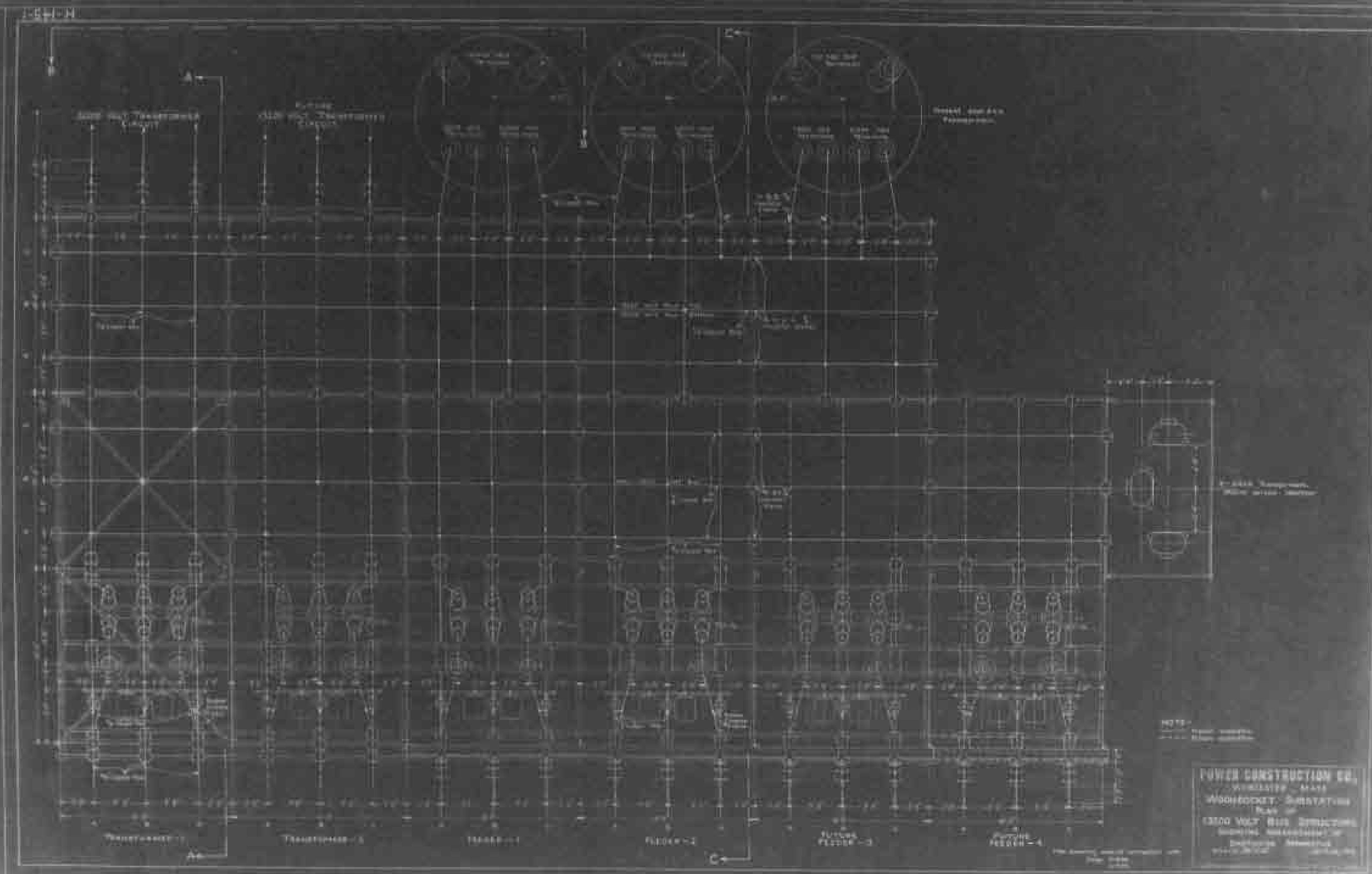
Woonsocket Substation High Tension Lines.



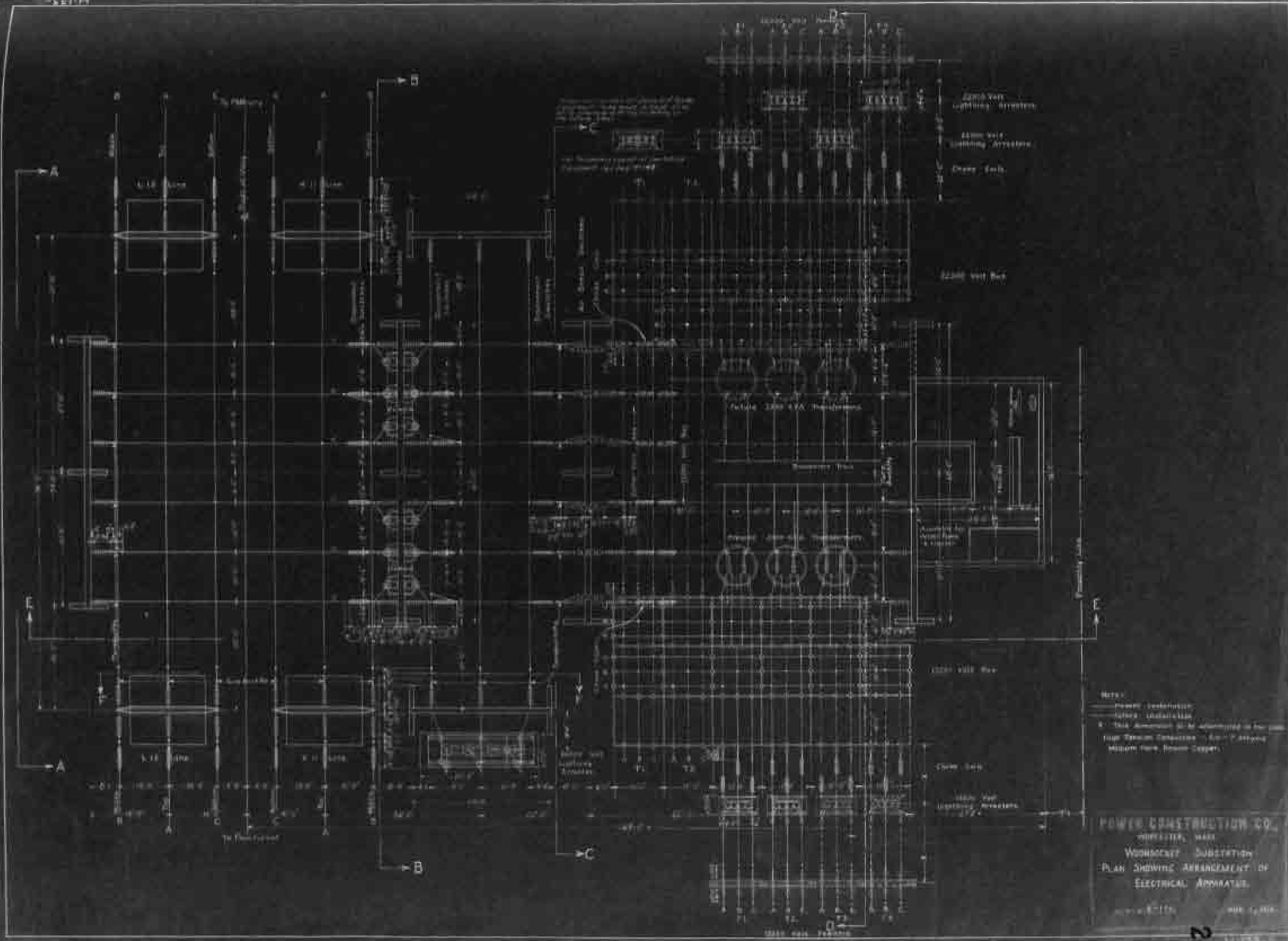
Woonsocket Substation Low Tension Bus Structure.


CROSS SECTION C.C.
ELEVATION THRU AA
ELEVATION THRU BB
POWER CONSTRUCTION CO.,
WORCESTER MASS.
WOONSOCKET SUBSTATION
33000 VOLT BUS STRUCTURE
SECTION & ELEVATIONS OF
FEEDER SWITCHING APPARATUS
C-536

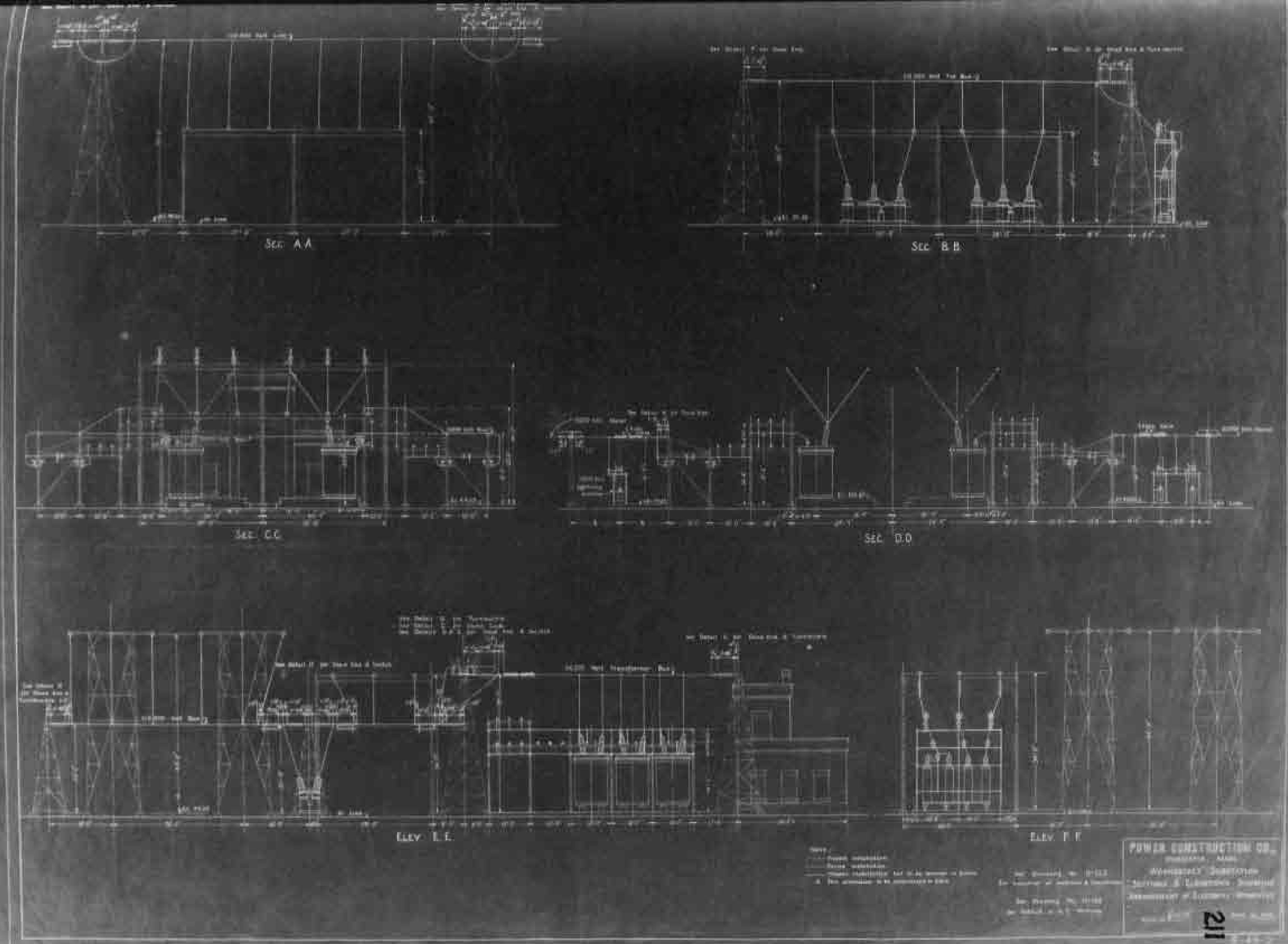
C 539

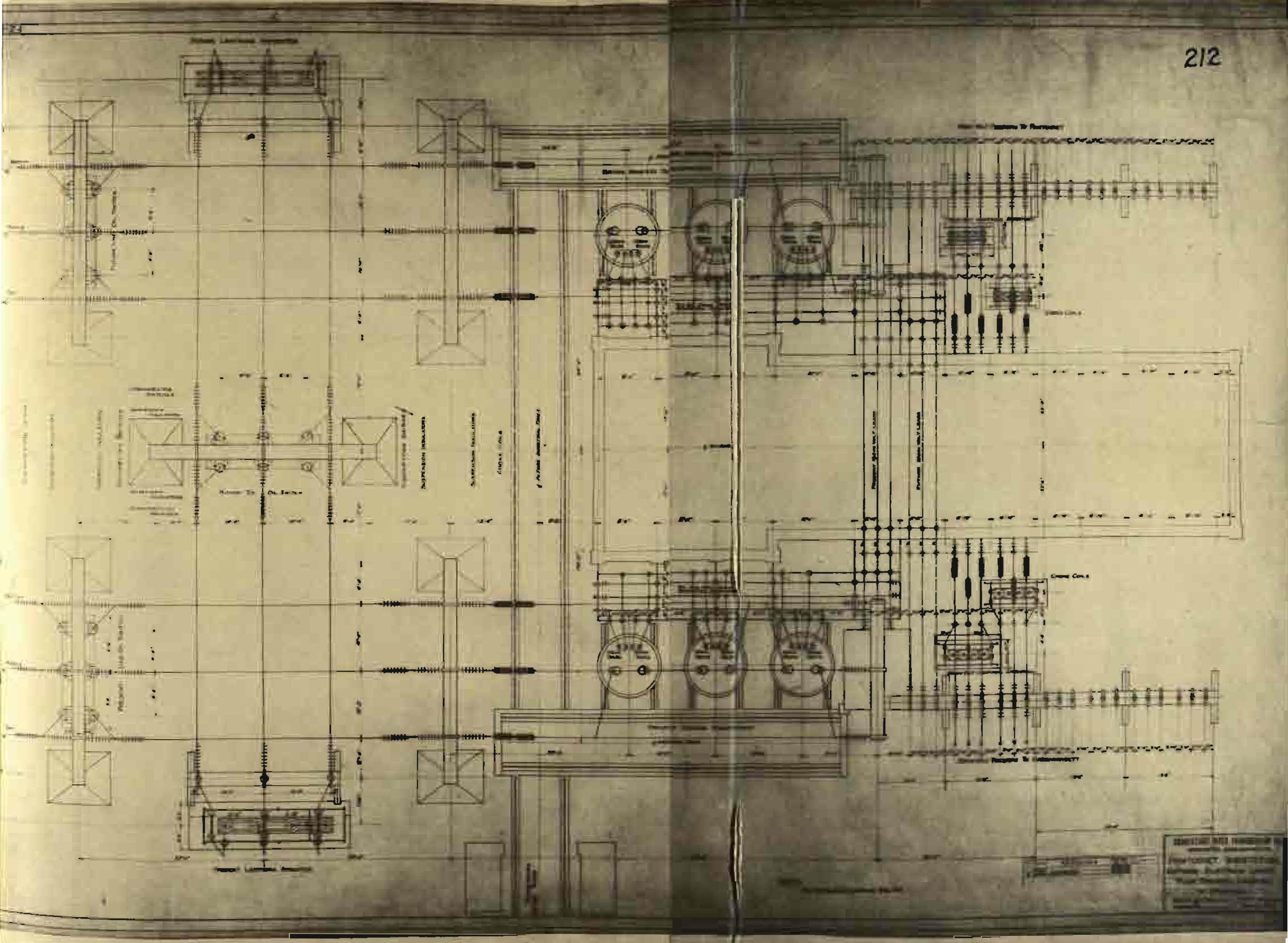


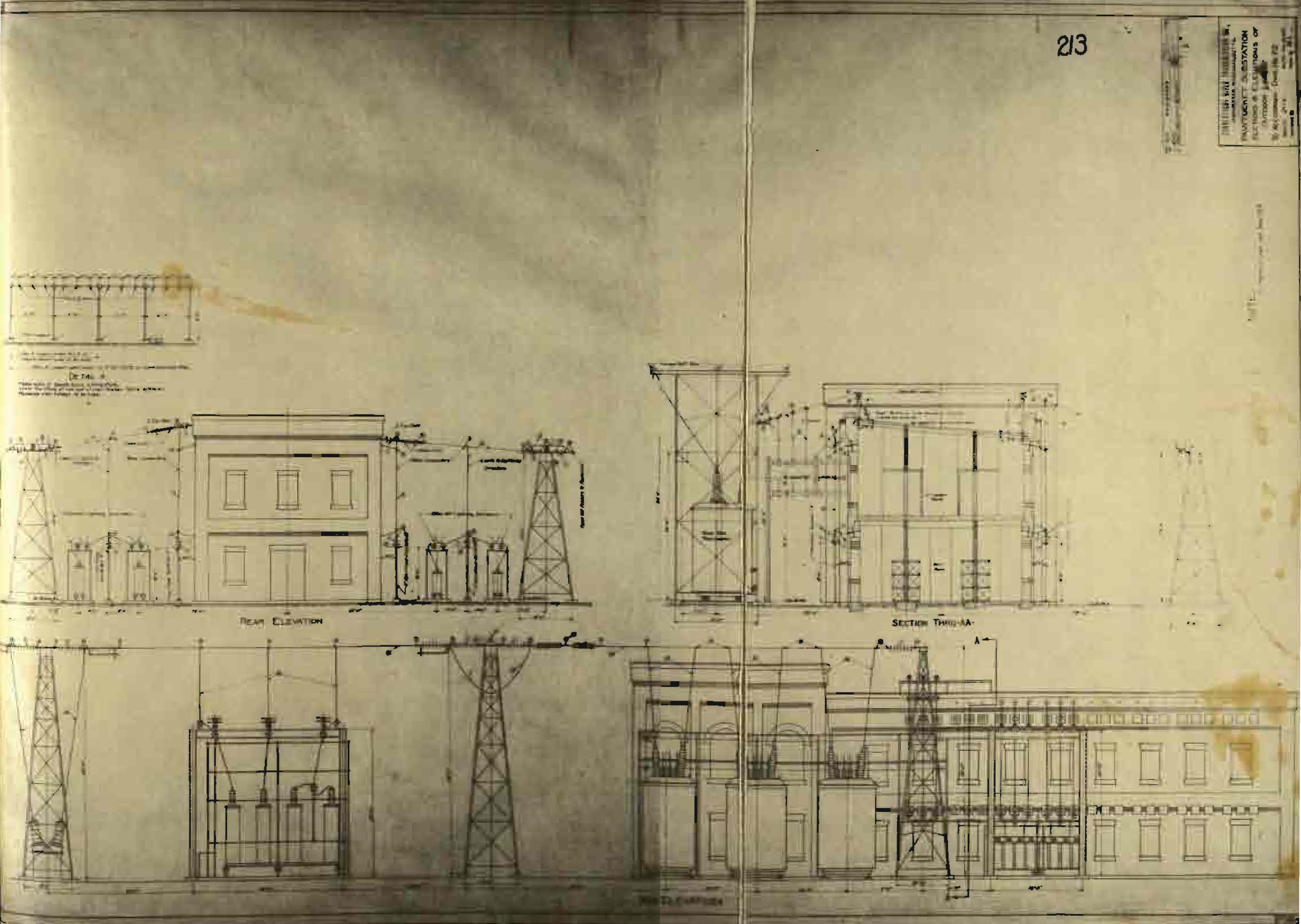
POWER CONSTRUCTION CO.,
WORCESTER, MASS.
WOONSOCKET SUBSTATION
PLAN OF
13200 VOLT BUS STRUCTURE
Transformer-1
Transformer-2
Feeder-1
Feeder-2
Future Feeder-3
Future Feeder-4

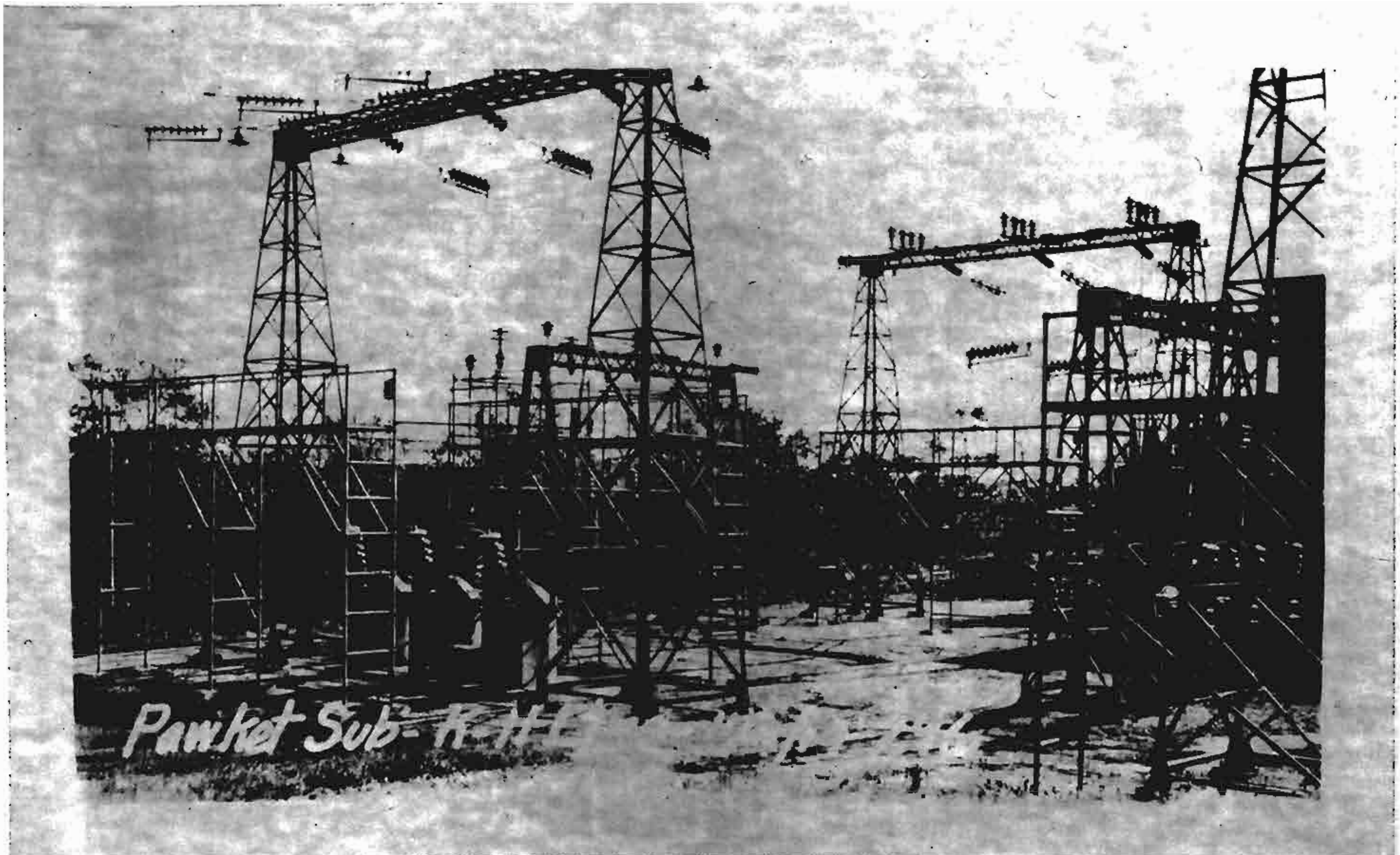


22000 Volt Lightning Arresters
Choke Coils
22000 Volt Bus
Note:
Present Installation
Future Installation
POWER CONSTRUCTION CO.
Woonsocket Substation
Plan Showing Arrangement of Electrical Apparatus.

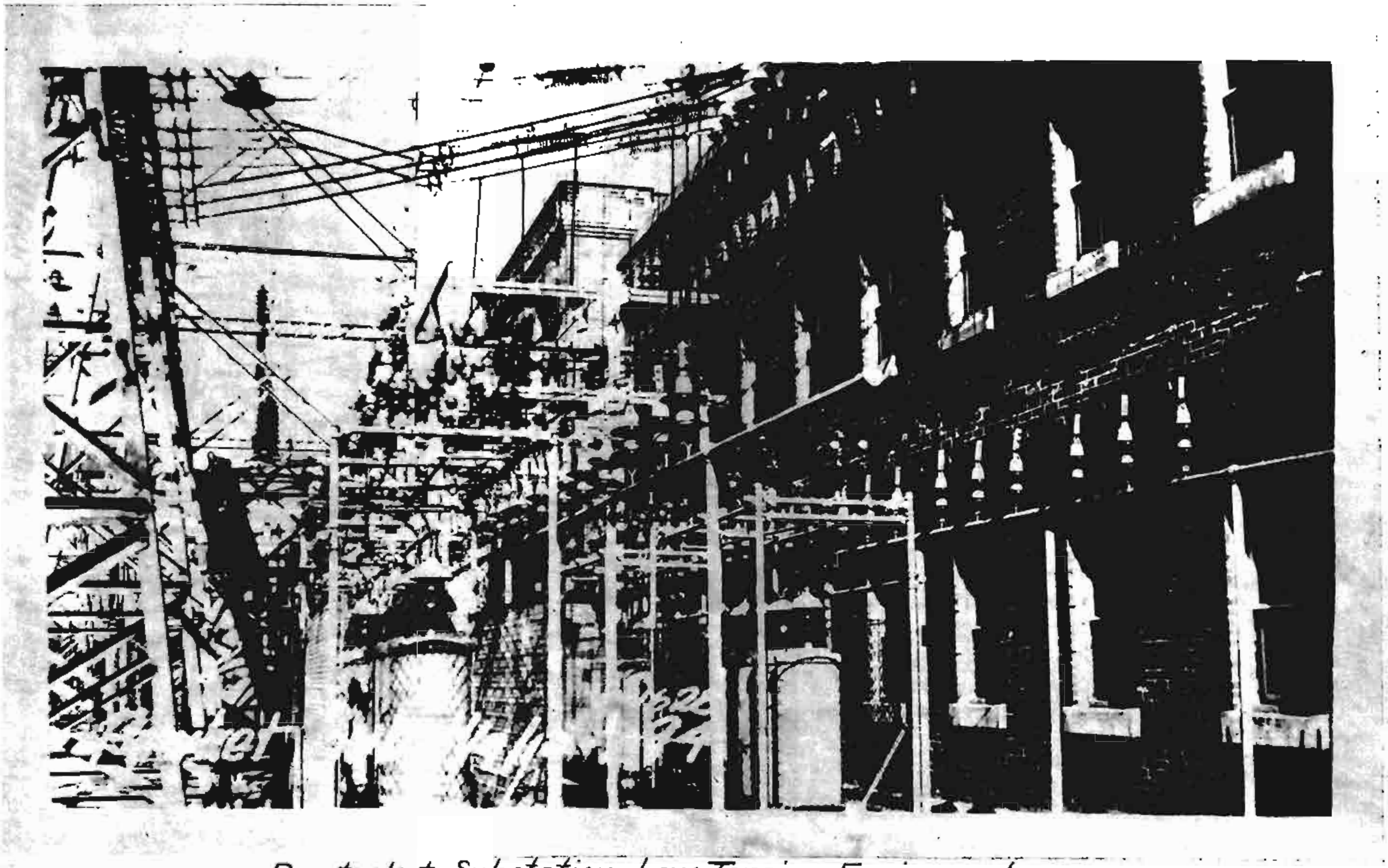

Sec. A.A
Sec. B.B
Sec. C.C
Sec. D.D
Elev. E.E
Elev. F.F
POWER CONSTRUCTION CO.
211



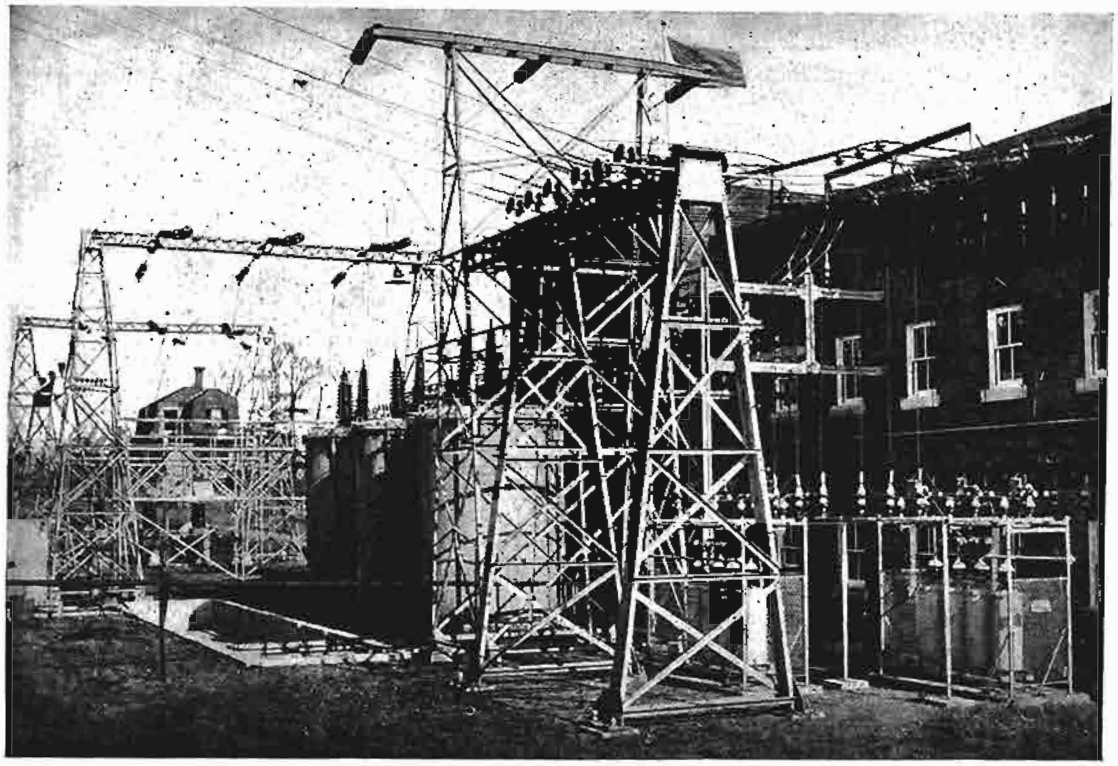

213
PAWTUCKET SUBSTATION
DETAIL A
REAR ELEVATION
SECTION THRU AA



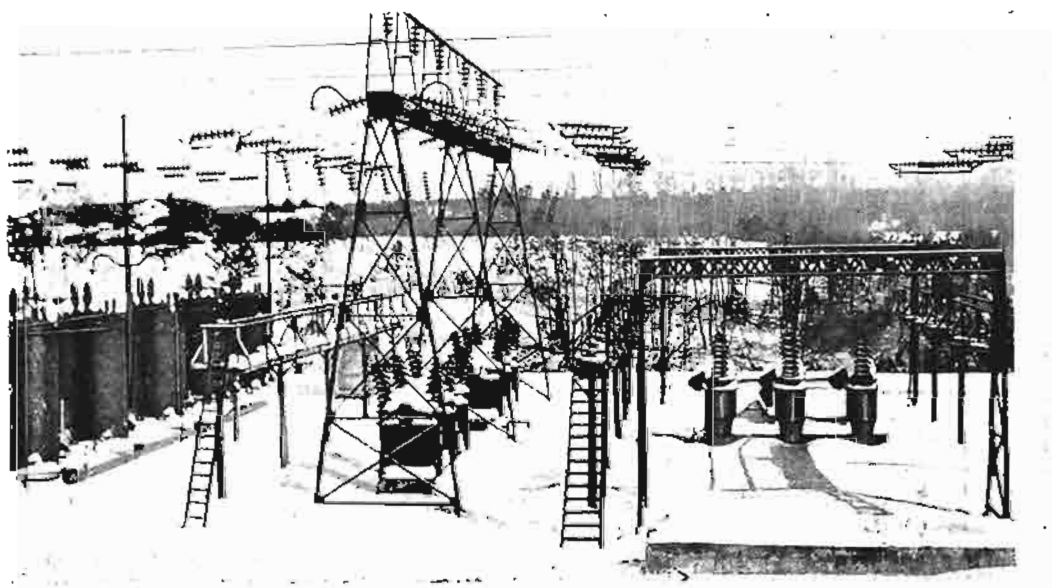
Pawtucket Substation High Tension Equipment.



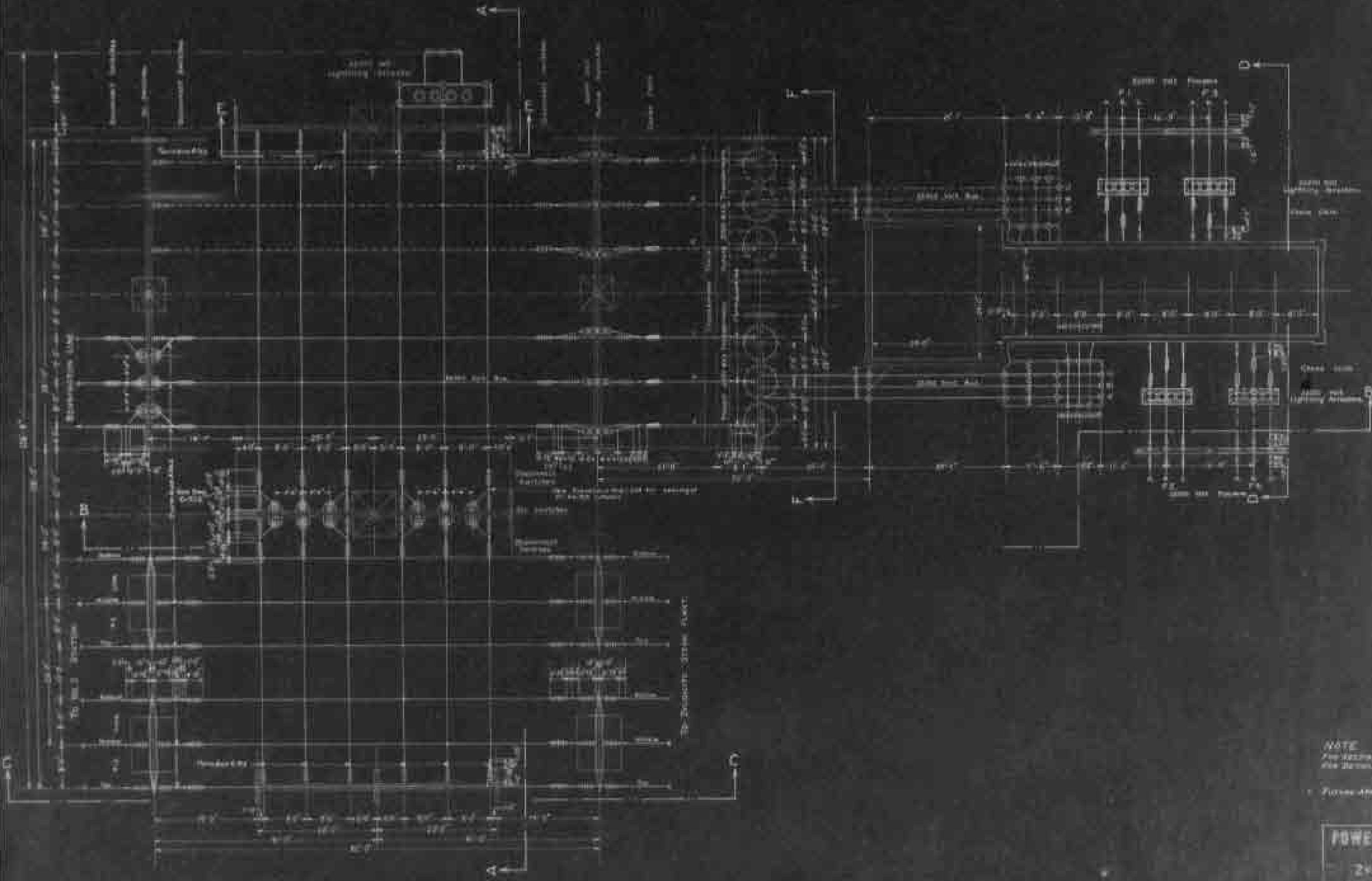
Pawtucket Substation Low Tension Equipment.



Pawtucket Substation - High & Low Tension Equipment.



Millbury Substation - In Winter.



NOTE

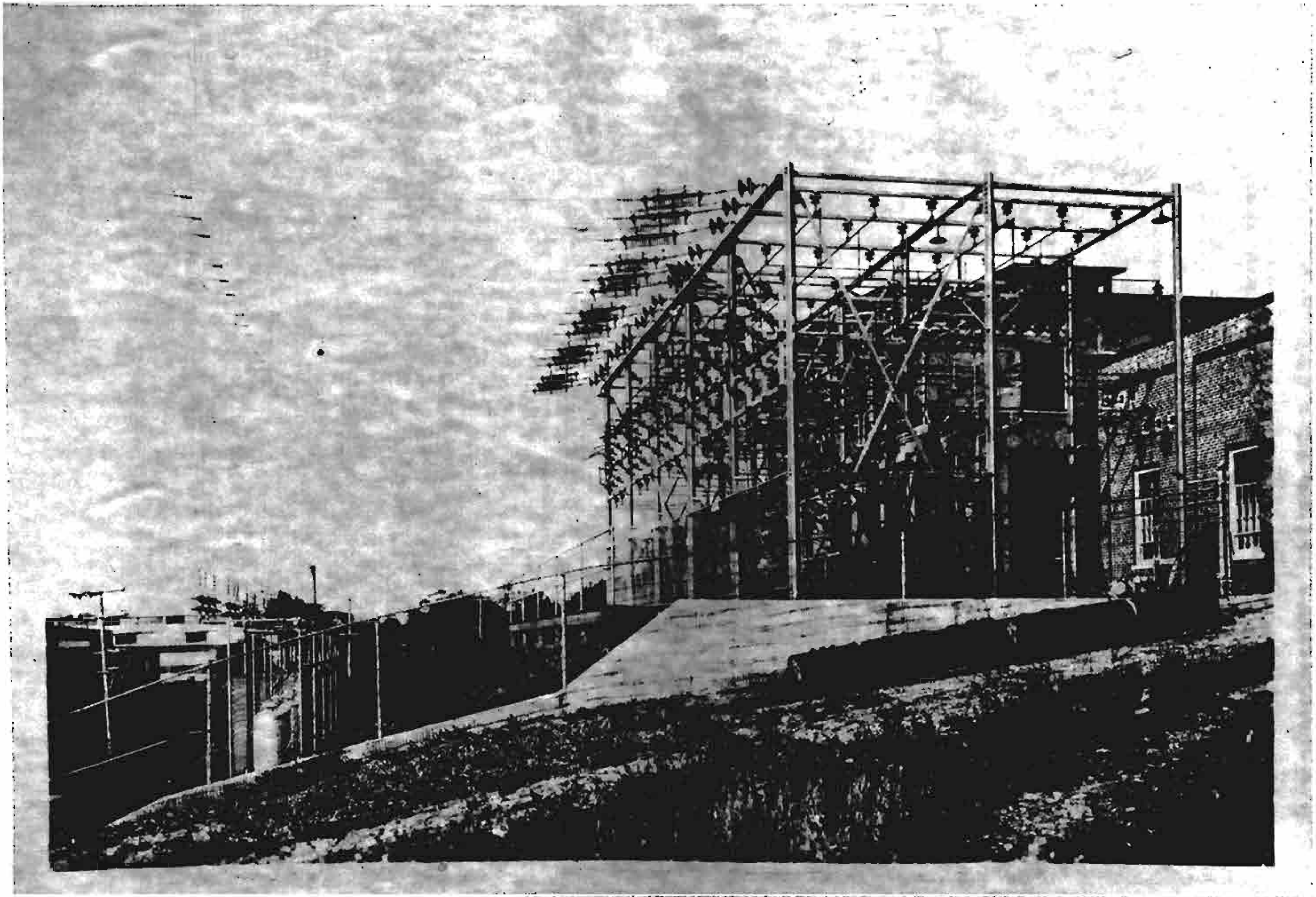
POWER CONSTRUCTION CO.

Outdoor Electrical Layout

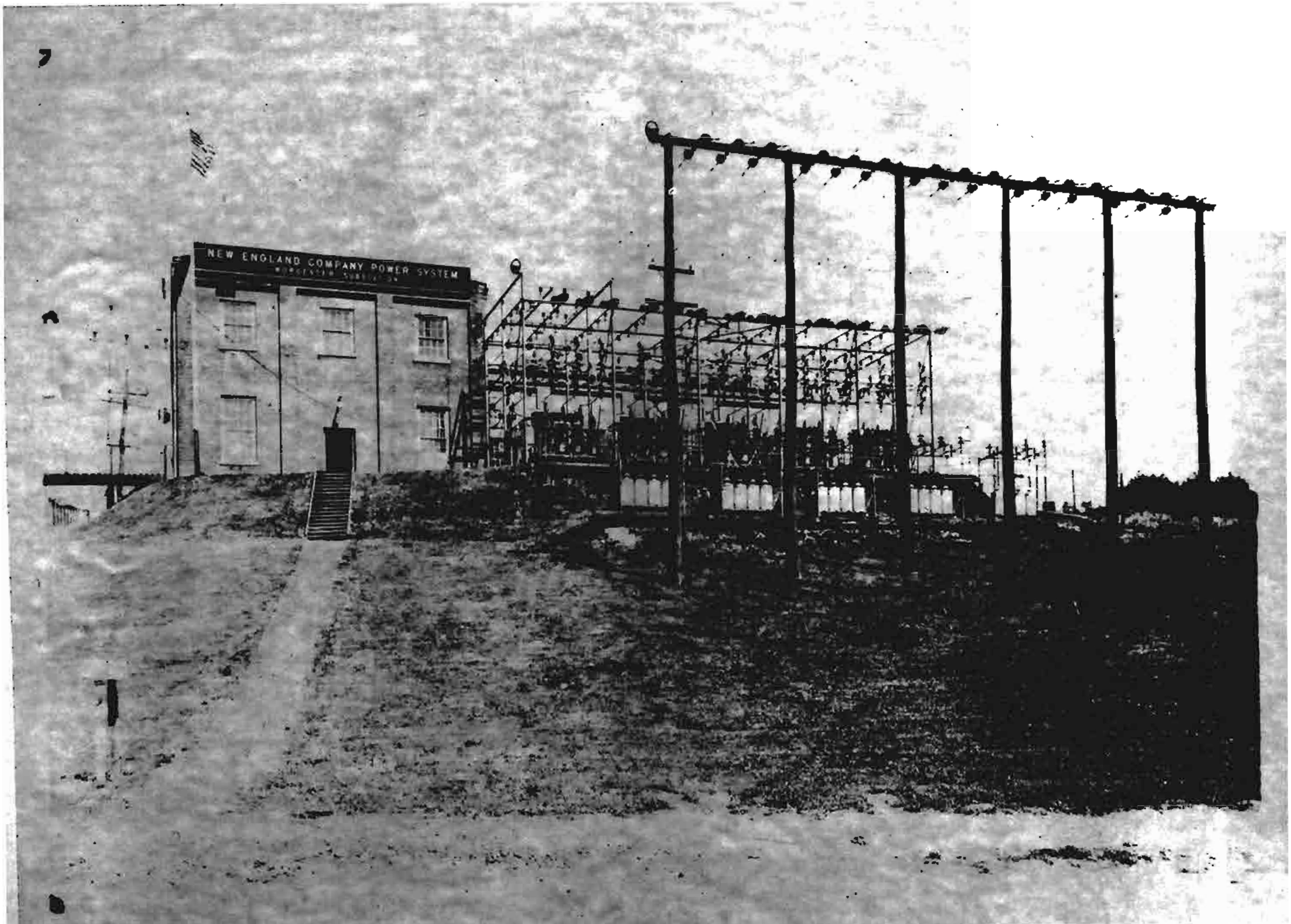
Showing Location of

217

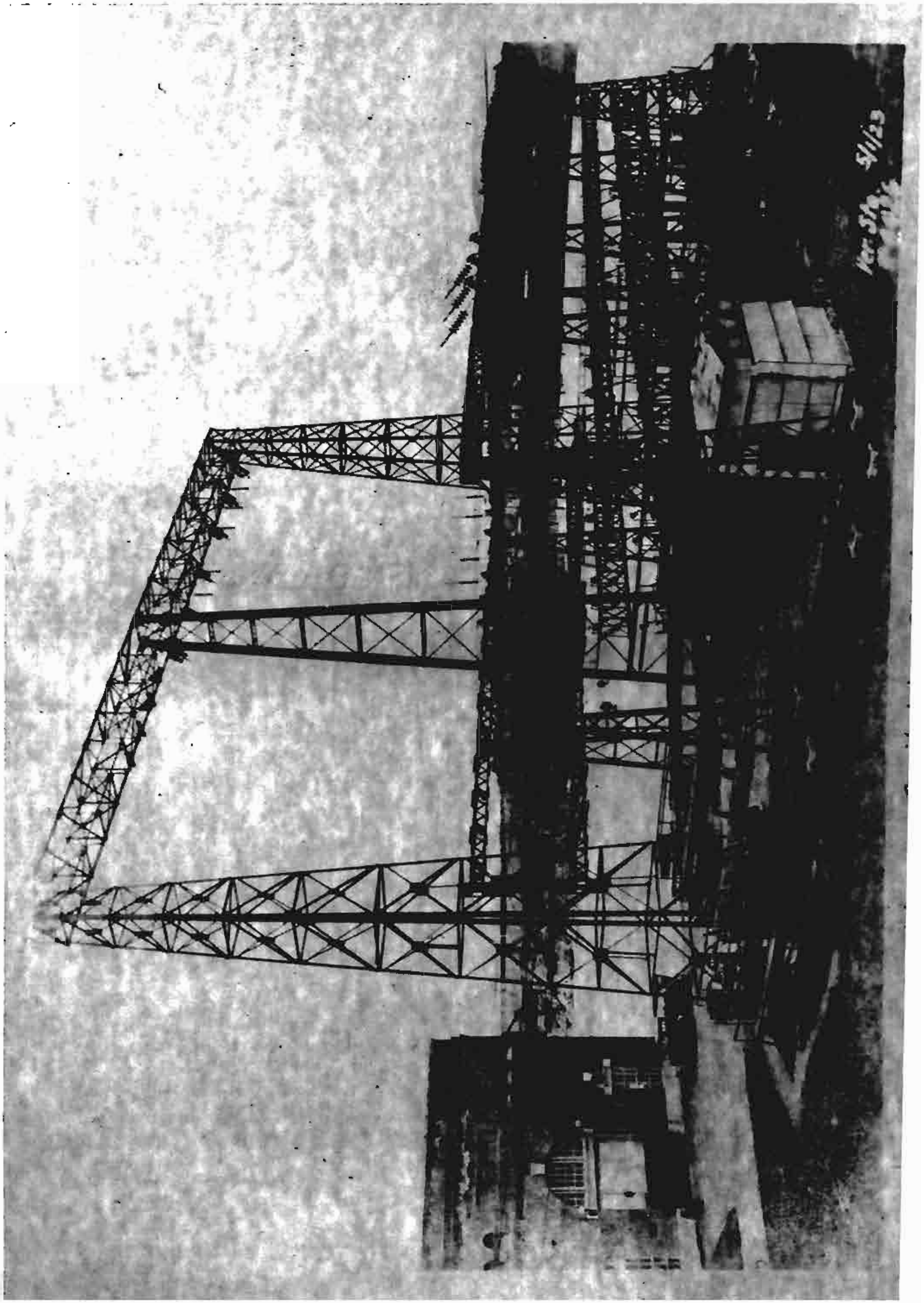

COM
LAYOUT



Worcester Substation - Low Tension Bus Structure.

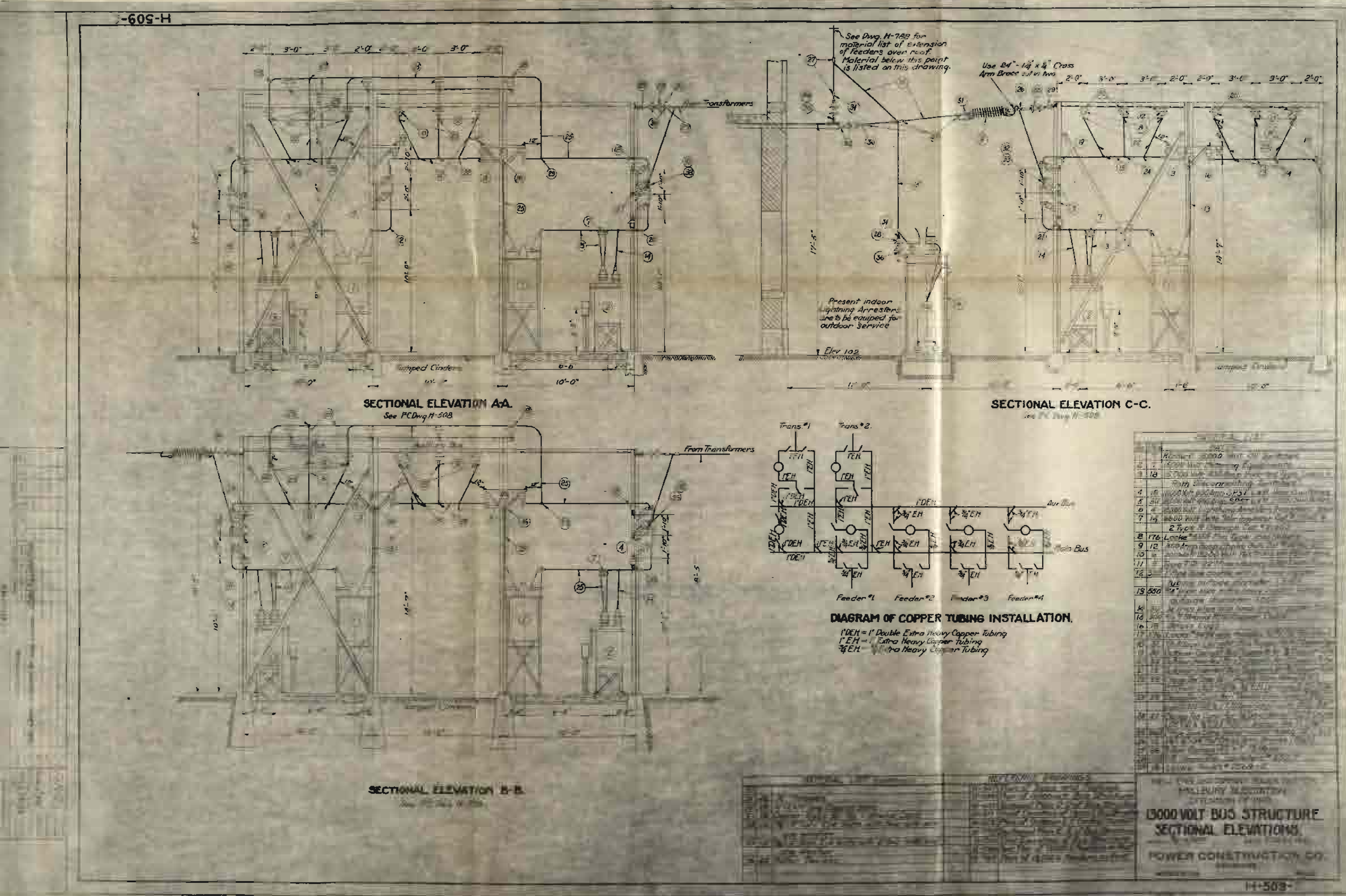


Worcester Substation - Low Tension Bus Structure.


5/1/23

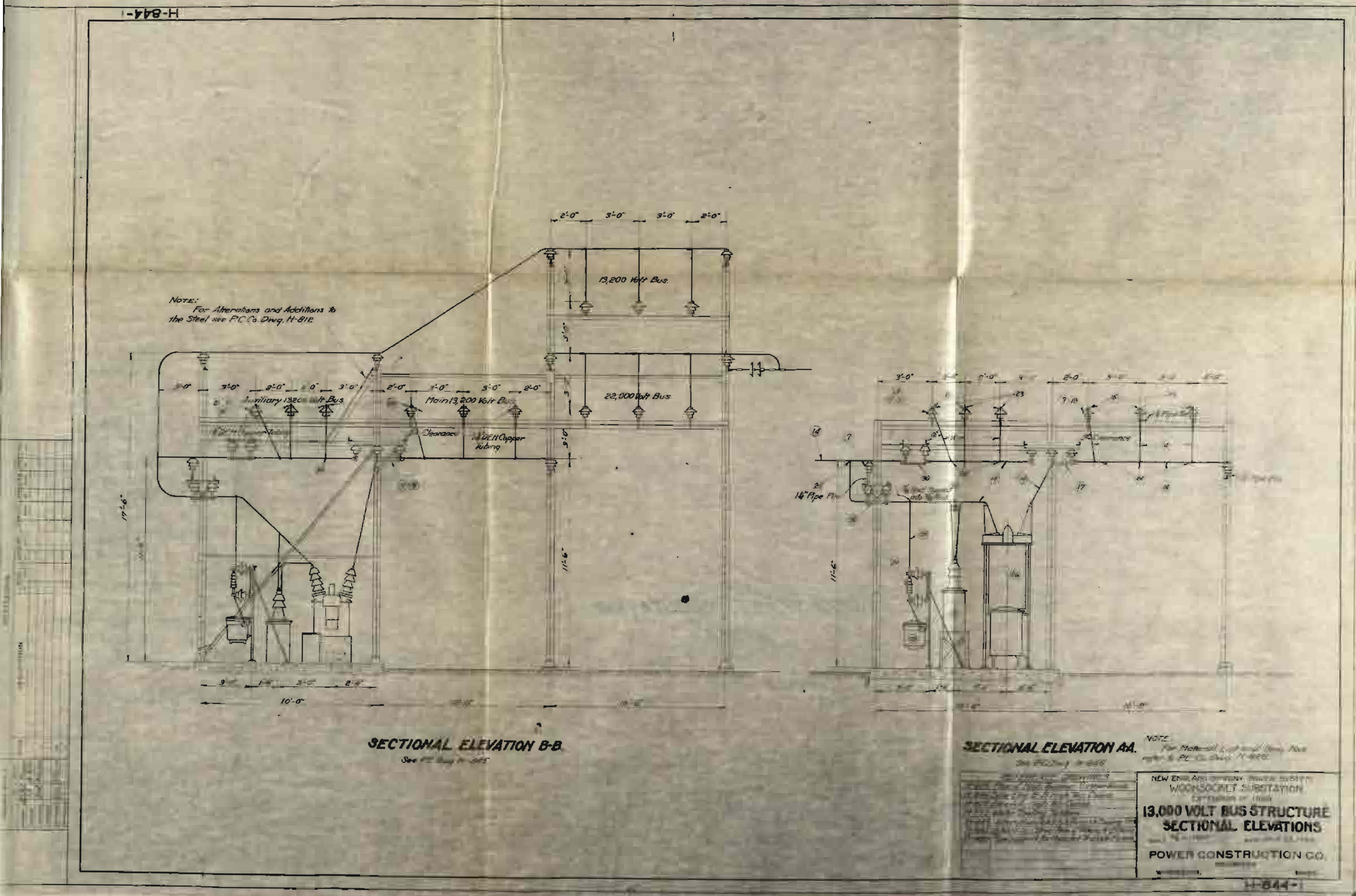
MILLBURY SUBSTATION

H-509.


H-509-
See Dwg. H-788 for material list of extension of feeders over roof. Material below this point is listed on this drawing.
Use 2¼" - 1¼" x ¼" Cross Arm Brace cut in two
Transformers
From Transformers
Tamped Cinders
Present indoor Lightning Arresters are to be equiped for outdoor service
Elev 102
SECTIONAL ELEVATION A-A.
See P.C.Dwg H-508
SECTIONAL ELEVATION C-C.
SECTIONAL ELEVATION B-B.
Trans #1
Trans #2
Aux Bus
Main Bus
Feeder #1
Feeder #2
Feeder #3
Feeder #4
DIAGRAM OF COPPER TUBING INSTALLATION.
1"DEH = 1" Double Extra Heavy Copper Tubing
1"EH = 1" Extra Heavy Copper Tubing
¾"EH = ¾" Extra Heavy Copper Tubing
13000 VOLT BUS STRUCTURE
SECTIONAL ELEVATIONS
POWER CONSTRUCTION CO.
H-509-

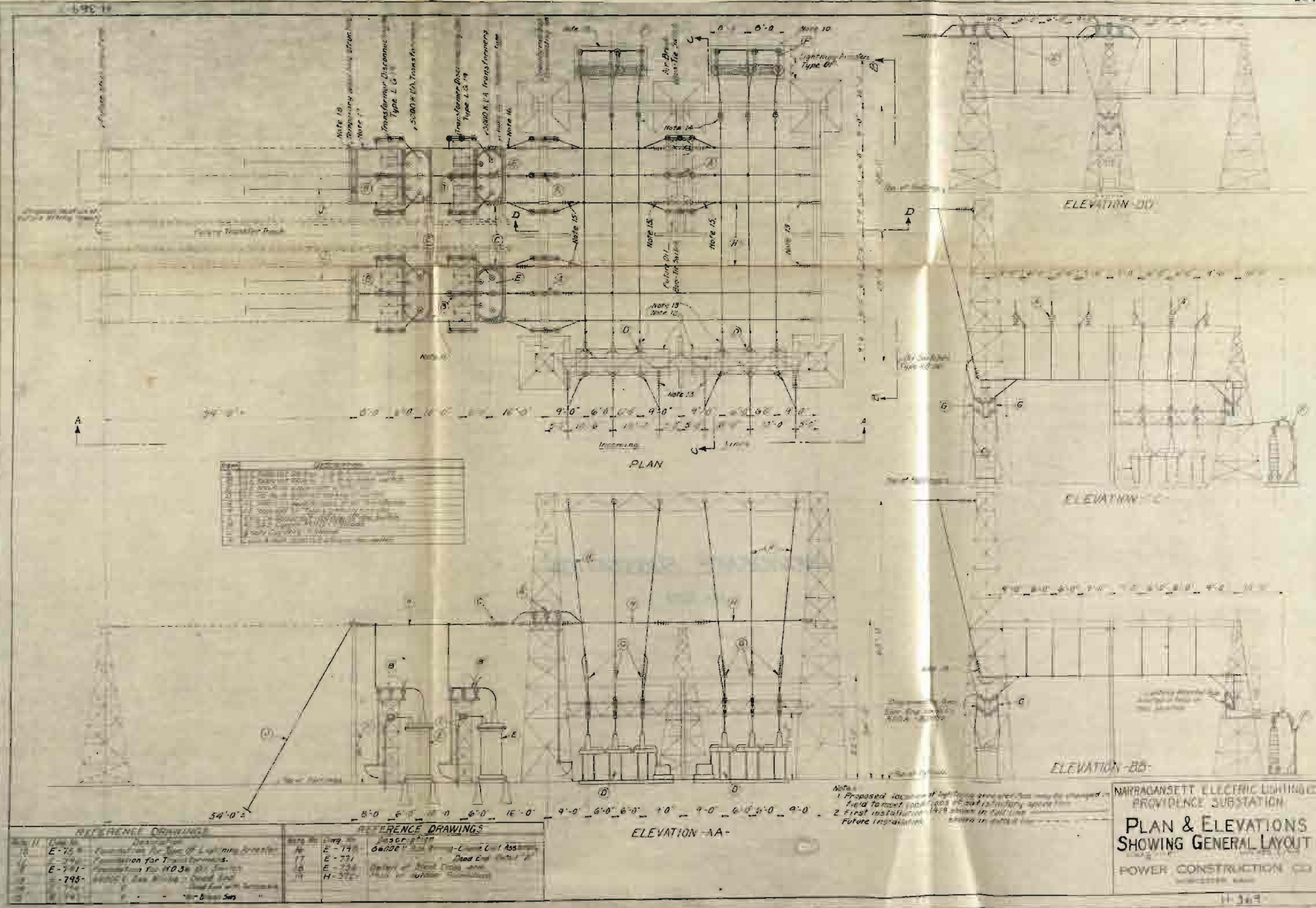
WOONSOCKET SUBSTATION

H-844.


H-844-1
NOTE:
For Alterations and Additions to the Steel see P.C. Co. Dwg. H-812.
2'-0" 3'-0" 3'-0" 2'-0"
13,200 Volt Bus.
22,000 Volt Bus
Main 13,200 Volt Bus
Clearance
Copper Tubing
17'-6"
11'-6"
10'-0"
1¼" Pipe
SECTIONAL ELEVATION B-B
SECTIONAL ELEVATION A-A.
NOTE:
NEW ENGLAND COMPANY
WOONSOCKET SUBSTATION
13,000 VOLT BUS STRUCTURE
SECTIONAL ELEVATIONS
POWER CONSTRUCTION CO.
H-844-1

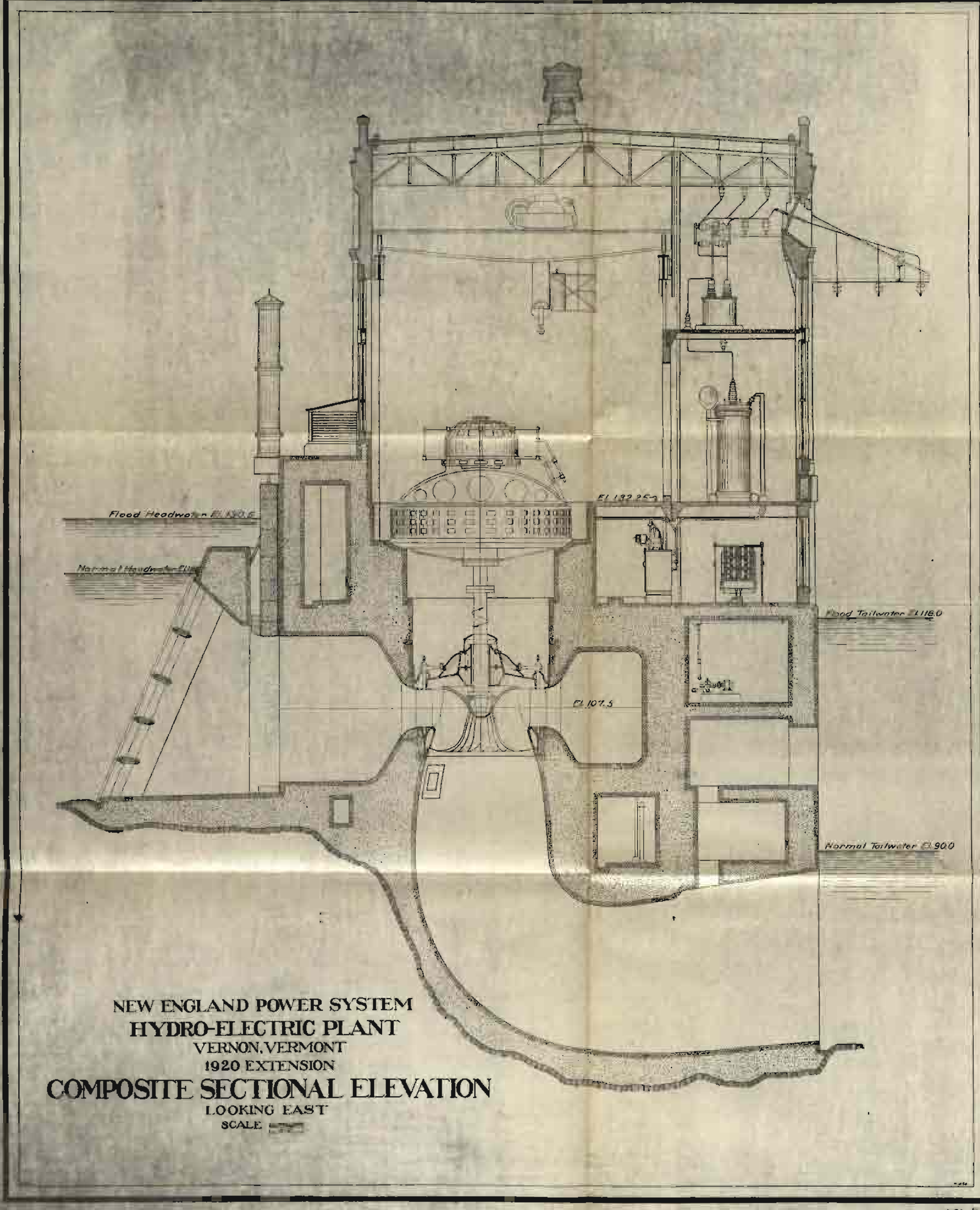
PROVIDENCE SUBSTATION

H-369.


PLAN
ELEVATION -AA-
ELEVATION -BB-
ELEVATION -CC-
ELEVATION -DD-
Transformer Disconnecting Type L G 19
Lightning Arrester Type OF
Note 13
Note 14
Note 15
Note 16
Incoming
Notes
1 Proposed location of lightning arrester may be changed in field to meet conditions of satisfactory operation
2 First installation shown in full line
Future installation shown in dotted line
REFERENCE DRAWINGS
E-75
Foundation for Transformers.
E-791-
E-795-
E-771
E-731
E-734
H-372
Dead End
NARRAGANSETT ELECTRIC LIGHTING CO
PROVIDENCE SUBSTATION
PLAN & ELEVATIONS
SHOWING GENERAL LAYOUT
POWER CONSTRUCTION CO
H-369

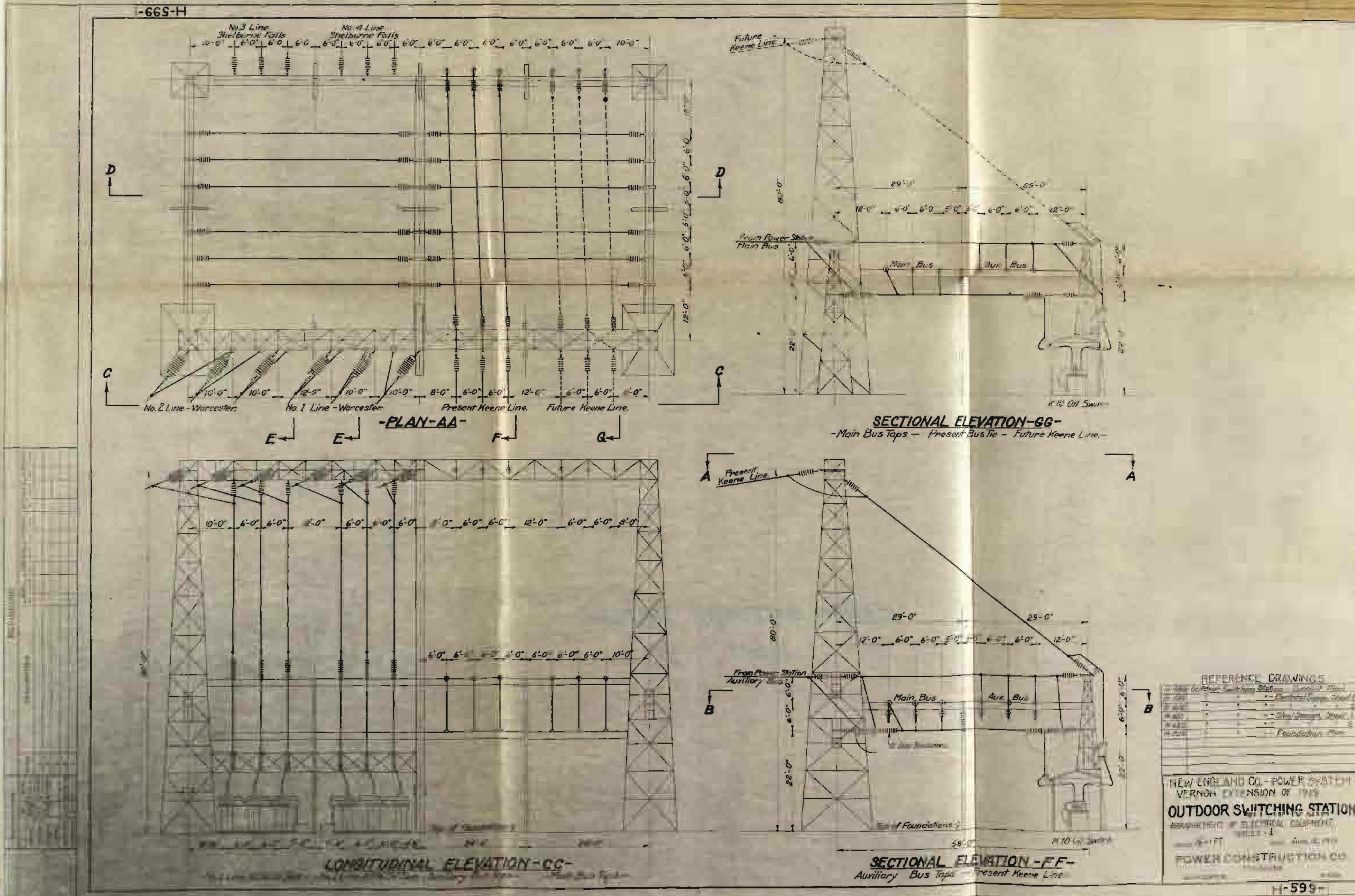
VERNON STATION

R-434.


Flood Headwater El. 130.6
Normal Headwater El.
El. 132.25
El. 107.5
Flood Tailwater El. 116.0
Normal Tailwater El. 90.0
NEW ENGLAND POWER SYSTEM
HYDRO-ELECTRIC PLANT
VERNON, VERMONT
1920 EXTENSION
COMPOSITE SECTIONAL ELEVATION
LOOKING EAST
SCALE

VERNON SWITCHING STATION

H-599.


H-599-
No. 3 Line Shelburne Falls
No. 4 Line Shelburne Falls
No. 2 Line - Worcester.
No. 1 Line - Worcester.
Present Keene Line.
Future Keene Line.
-PLAN-AA-
Future Keene Line
From Power Station Main Bus
Main Bus
Aux. Bus
SECTIONAL ELEVATION-GG-
-Main Bus Taps — Present Bus Tie — Future Keene Line.-
Present Keene Line.
From Power Station Auxiliary Bus
LONGITUDINAL ELEVATION-CC-
SECTIONAL ELEVATION-FF-
Auxiliary Bus Taps — Present Keene Line
REFERENCE DRAWINGS
NEW ENGLAND CO. - POWER SYSTEM
VERNON EXTENSION OF 1919
OUTDOOR SWITCHING STATION
POWER CONSTRUCTION CO.
H-599-

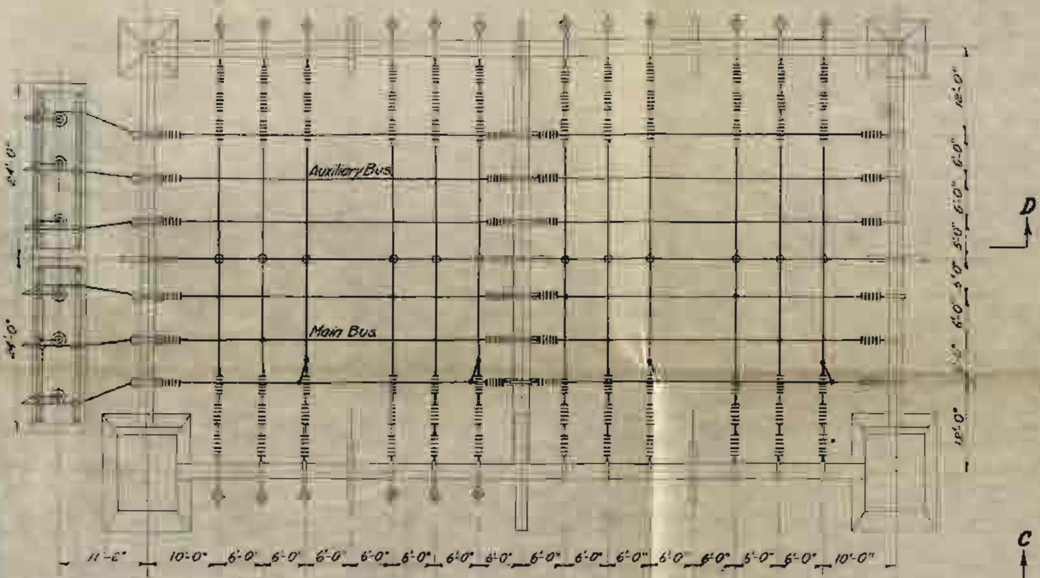
VERNON SWITCHING STATION.

H-600.

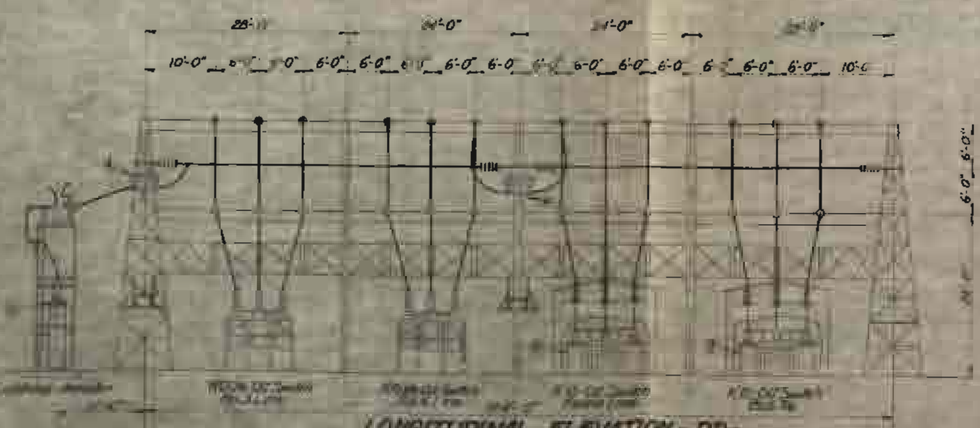
1-009-H

MATERIAL LIST.

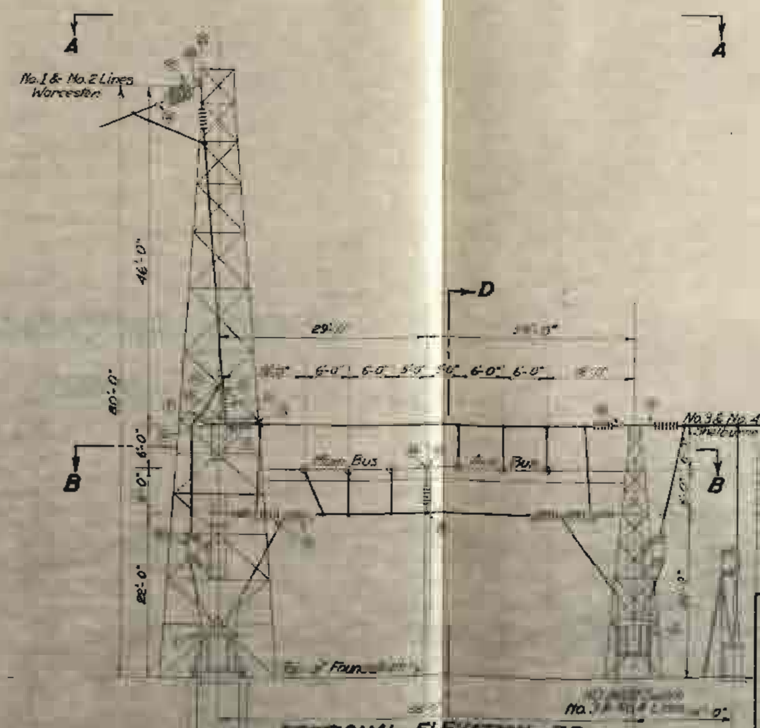
Item	DESCRIPTION	Quantity
1	Oil Switch - KO 36 - 70,000 V.	[illegible]
2	" " - KO26 - 70,000 V. - Present Switches equipped for outdoor service.	2
3	Oil Switch - K 10	[illegible]
4	Disconnecting Swtch - Delta Star, type F.B-2, 70,000 V. [illegible]	[illegible]
5	" " " Drg. 18204 EF- [illegible]	[illegible]
6	" " A & J.M. Anderson - for 6 Disc Insulators	[illegible]
7	Potential Transformers [illegible]	[illegible]
8	Lighting Arrester - Electrolytic - Present Arresters equipped for outdoor service	2
9	Pin Insulator [illegible] #13221 - 88,000 V	[illegible]
10	Lec. Pin # 124 [illegible]	[illegible]
11	Suspension Insulator [illegible] Locke # 5757	[illegible]
12	[illegible] Locke # [illegible]	24
13	[illegible] Locke # [illegible]	36
14	[illegible] - Locke # [illegible]	12
15	[illegible] Locke # [illegible]	12
16	[illegible]	[illegible]
17	Thimble [illegible]	[illegible]
18	Turnbuckles [illegible] $\frac{5}{8}$"	42
19	[illegible]	[illegible]
20	[illegible] 1" x 12	6
21	[illegible] $\frac{3}{4}$ x 12"	[illegible]
22	Suspension [illegible]	[illegible]
23	Cross [illegible] (-799)	[illegible]
24	[illegible]	[illegible]
25	[illegible] Clevis	[illegible]



SECTIONAL PLAN-BB-



LONGITUDINAL ELEVATION-DD-



SECTIONAL ELEVATION-EE-

REFERENCE DRAWINGS

H-598	Outdoor Switching Station - General Plan
H-599	" " " Electrical Equip. Sheet 1
H-600	" " " " " 2
H-6[illegible]	" " " Steel Design, Sheet 1
H-62[illegible]	" " " " " 2
H-70[illegible]	" " " [illegible]

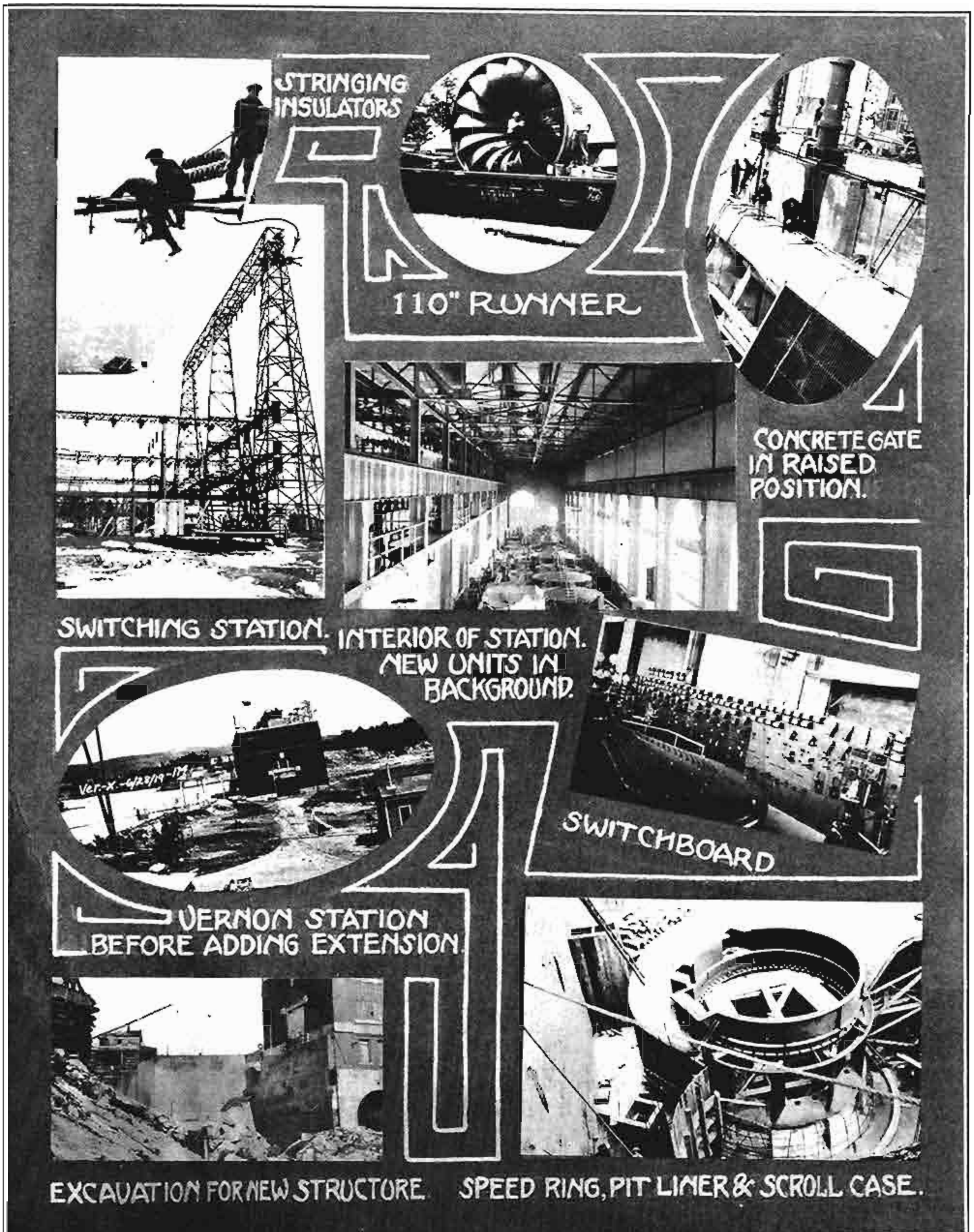
NEW ENGLAND CO. POWER SYSTEM
VERNON EXTENSION OF 1919

OUTDOOR SWITCHING STATION

ARRANGEMENT OF ELECTRICAL EQUIPMENT
SHEET-2-

POWER CONSTRUCTION CO.

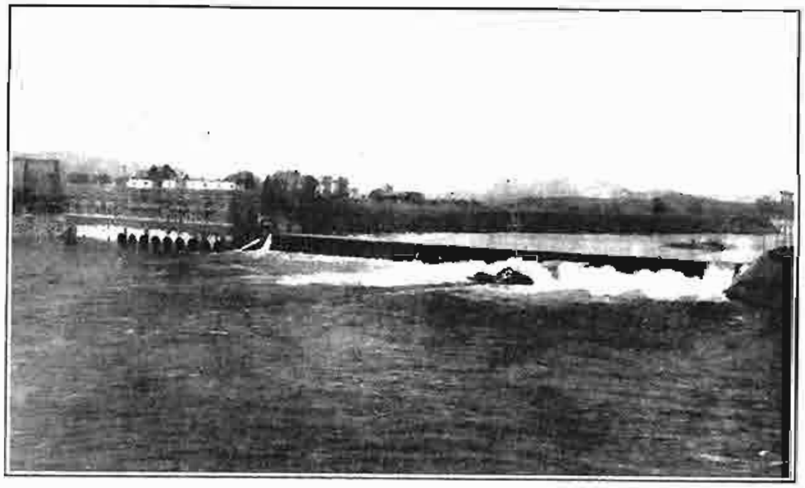
H-600-



Vernon Power Station & Switching Station.

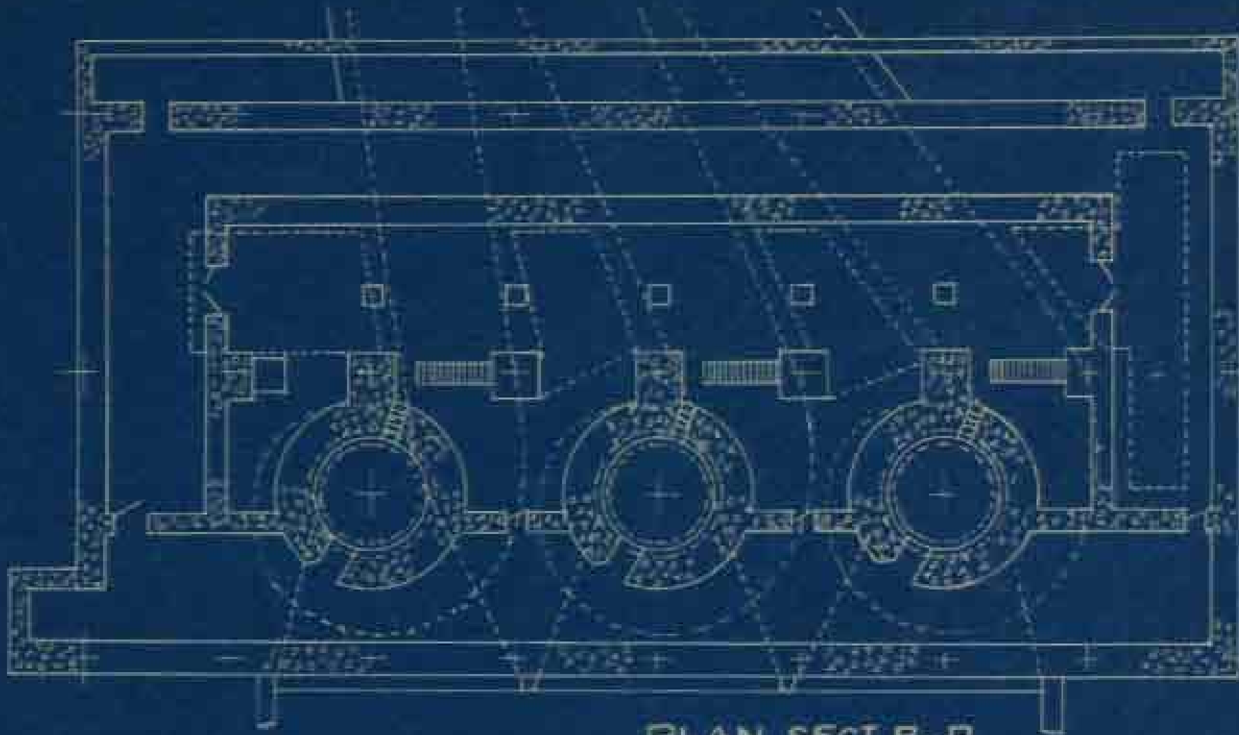
CONTACT

PUBLISHED BY NEW ENGLAND COMPANY POWER SYSTEM



THE VERNON PLANT, SHOWING EXTENSION AND SWITCHING STATION ON THE LEFT

MARCH, 1921



PLAN SECT. B-B

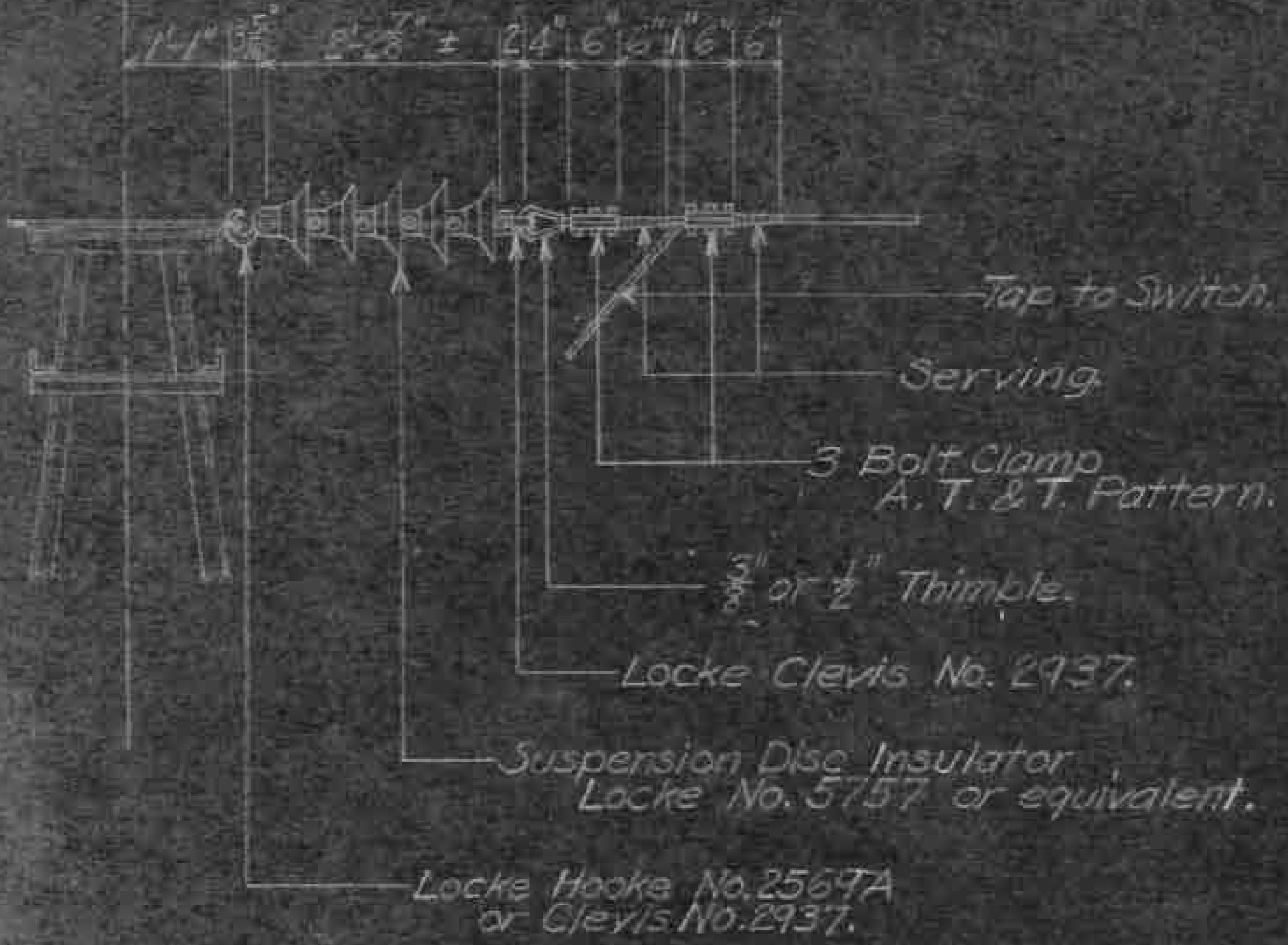
TYPICAL SECTION

BELLOWS FALLS PLANT
POWER HOUSE SECTIONS

SCALE 1" = 30' DATE Nov. 18, 1918

POWER CONSTRUCTION CO., ENGRS.
WORCESTER, MASS.

E-731-1



DEAD END AT STEEL TOWER
66000-VOLT SUBSTATION BUS WIRING.

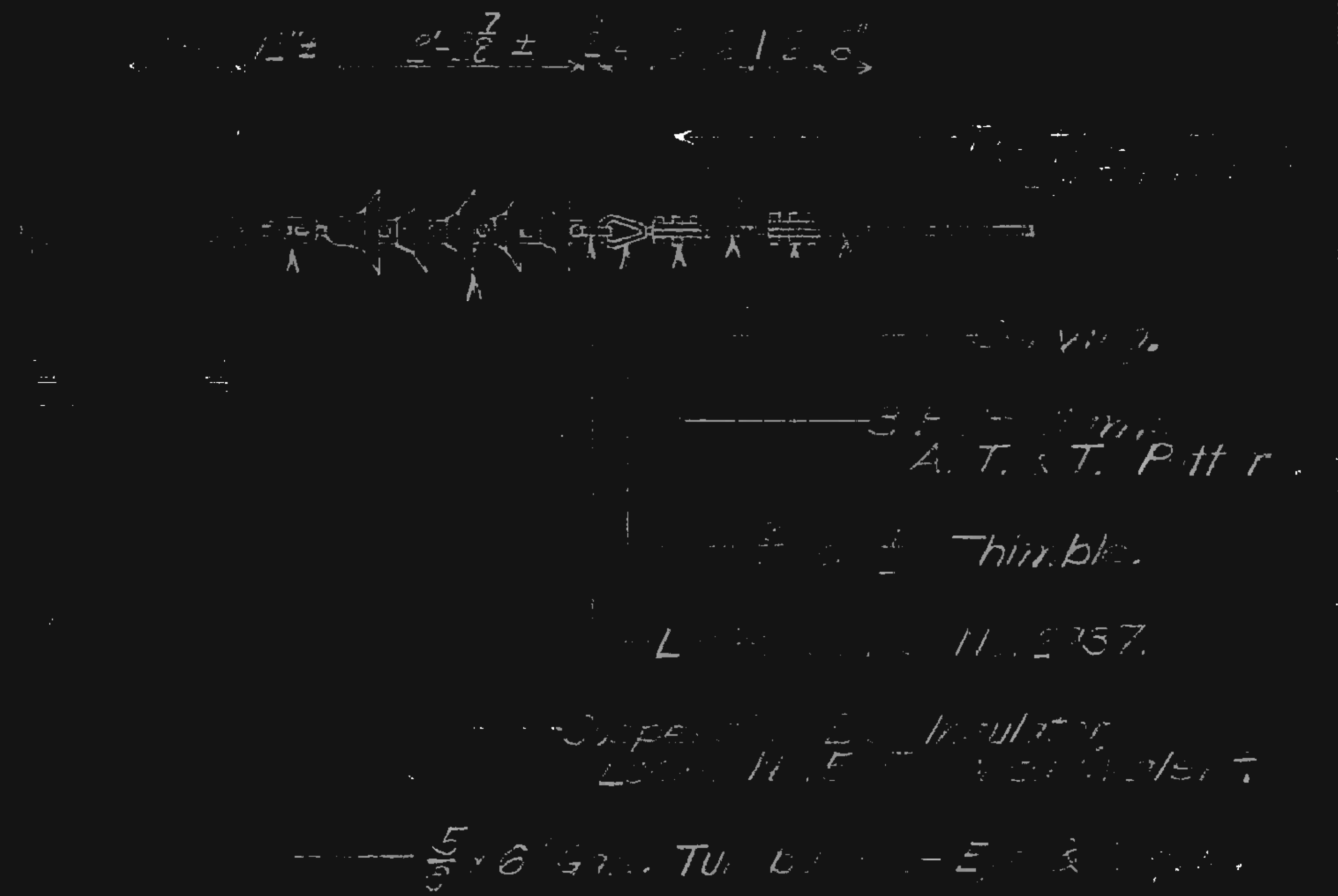
NOTES:

1. Omit tap to switch when it is not required.
2. For 110,000 V. installation use 7 discs.
3. For 11,000 V. & 22,000 V. " " 2 " .

STANDARD BUS WIRING
SHEET No. 5.

SCALE 1/8" = 12" DATE: FEB. 7, 1923
OUTDOOR SUBSTATIONS
T.H. LOVETT.

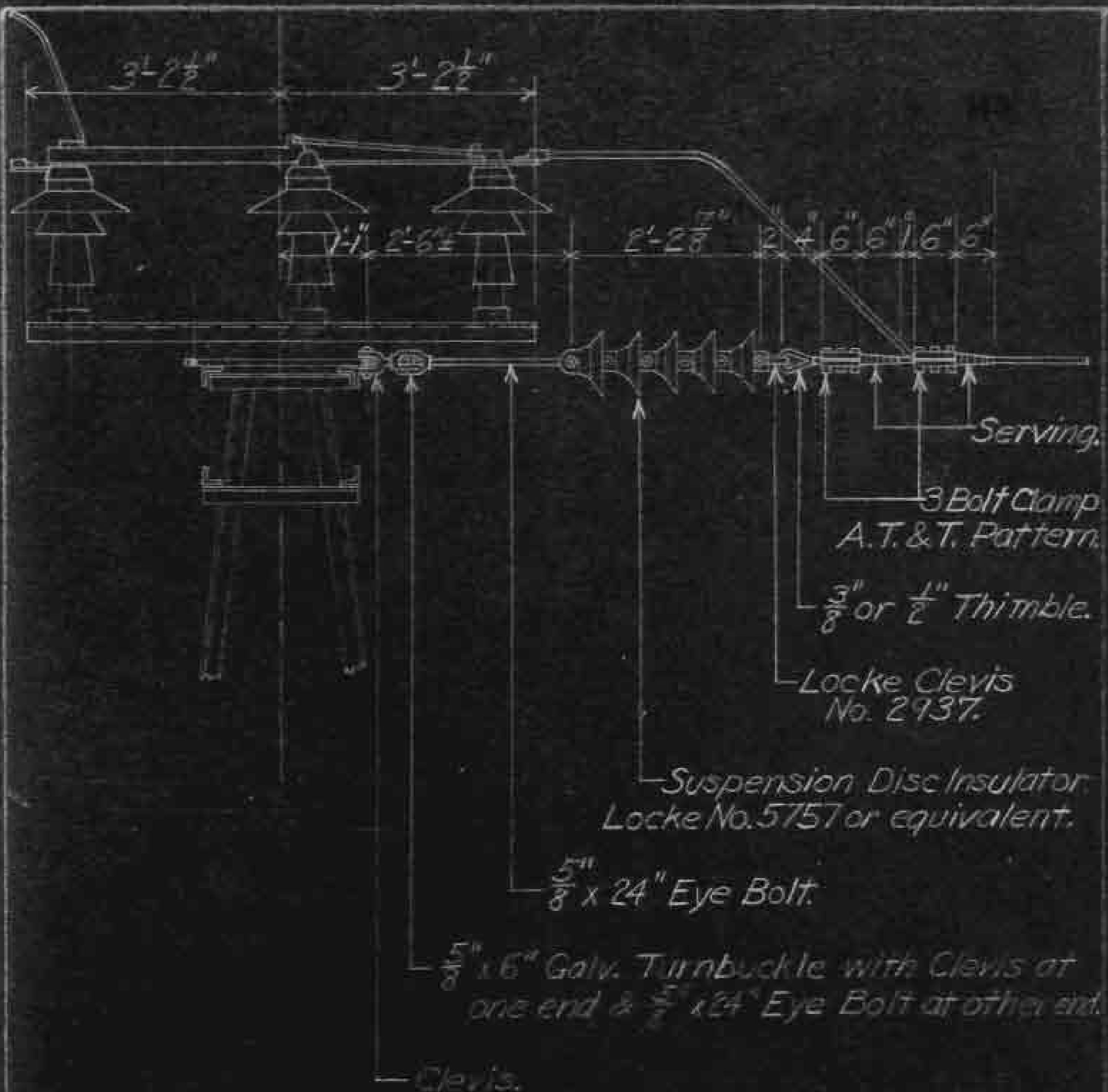
E-796-1



DEAD END WITH TURNBUCKLE
6[illegible] VOLT SUBSTATION BUS WIRING.

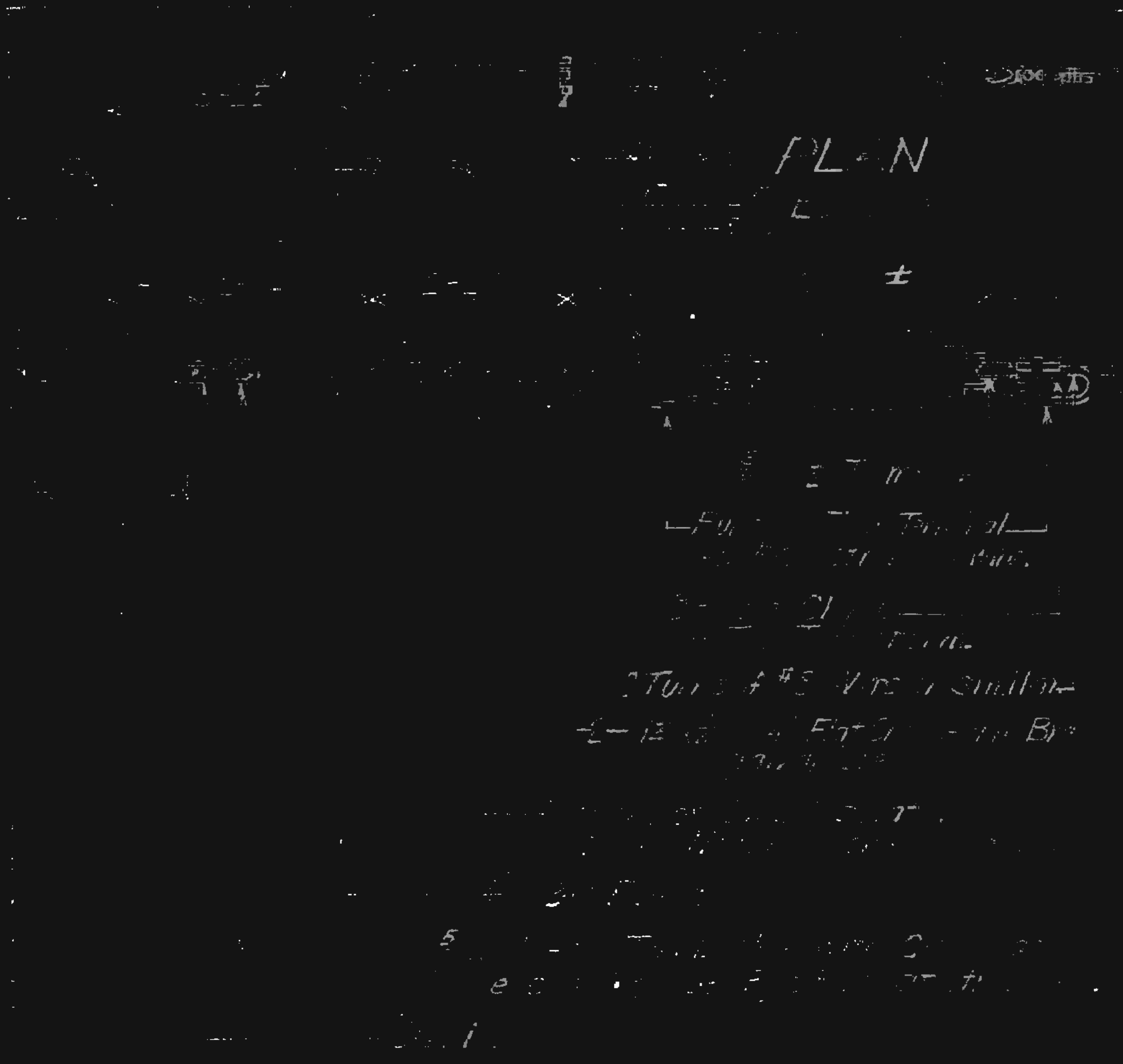
STANDARD BUS WIRING
SHEET No. 6.

E-777-1



AIR BREAK SWITCH WITH TURNBUCKLE
66[illegible] VOLT SUBSTATION BUS WIRING

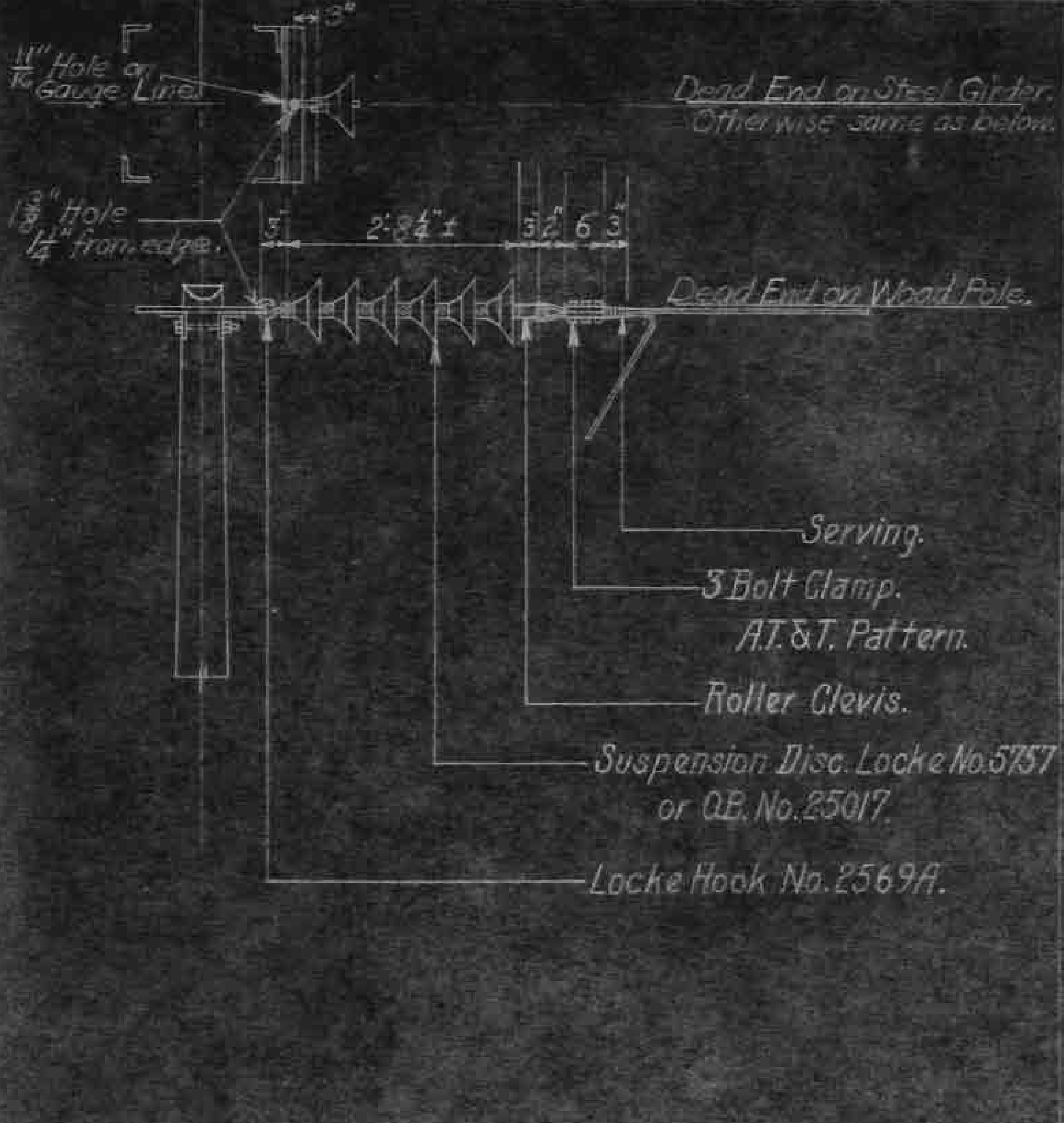
STANDARD BUS WIRING
SHEET [illegible]
DATE 6-[illegible]
[illegible]18-1



CHOKE COIL ASSEMBLY.
66000 VOLT SUBSTATION BUS WIRING.

STANDARD BUS WIRING
SHEET No. 8.
SCALE: $\frac{1}{2}$" = 1' 0" DATE: 3-2-23
OUTDOOR SUBSTATIONS
I.H. LOVETT.

E-799-1

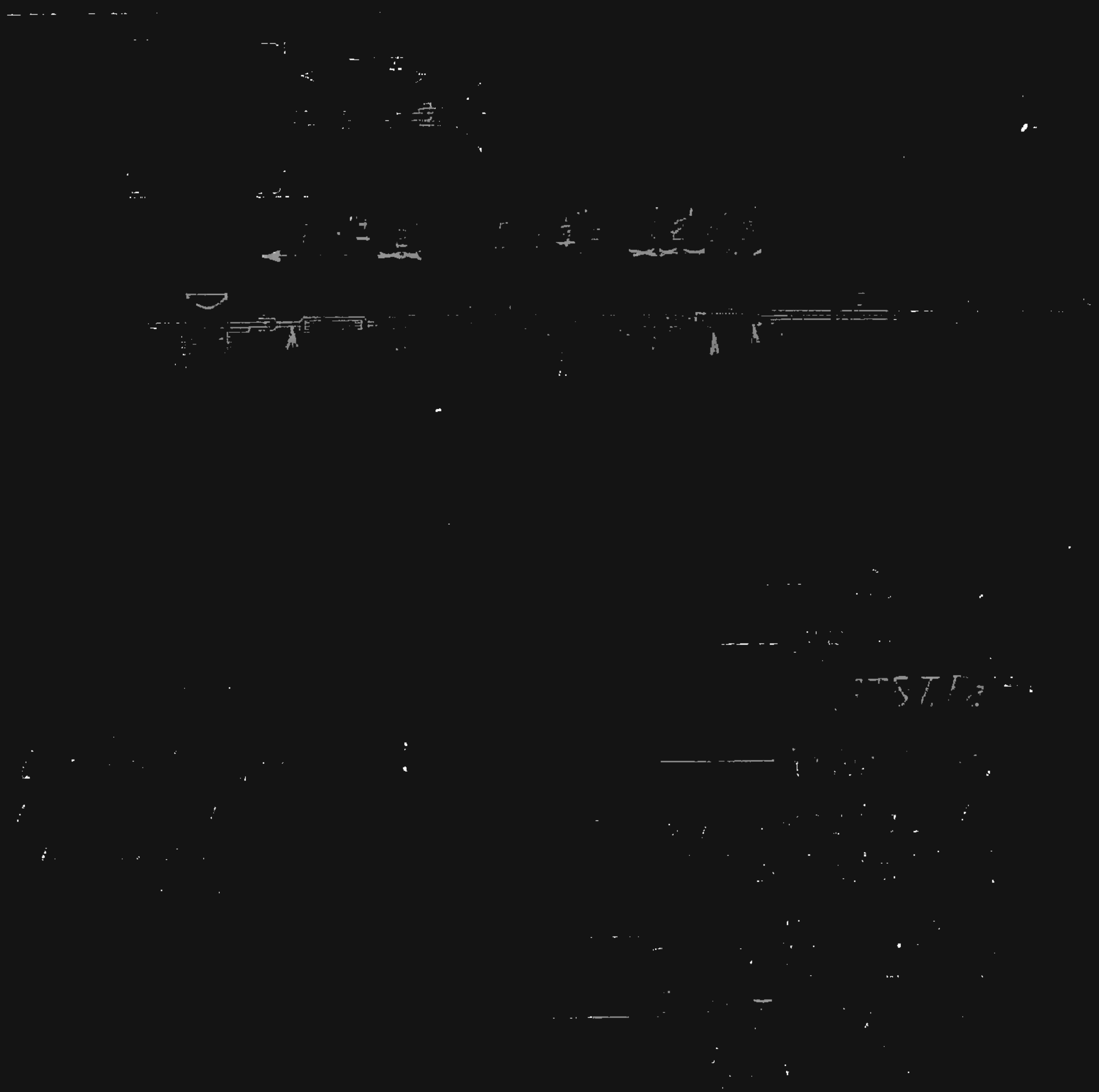


Dead End with Hook for 66000-Volt Substation Bus Wiring.

Notes.
1. For 110,000 Volt installations use 7 discs.
2. For 11,000 & 22,000 Volt installations use 2 discs.

STANDARD BUS WIRING
SHEET NO. 11.
SCALE: 1/2" = 1'-0" DATE: 3-2-23
OUTDOOR SUBSTATIONS
I. H. LOVETT.

E-1182-1

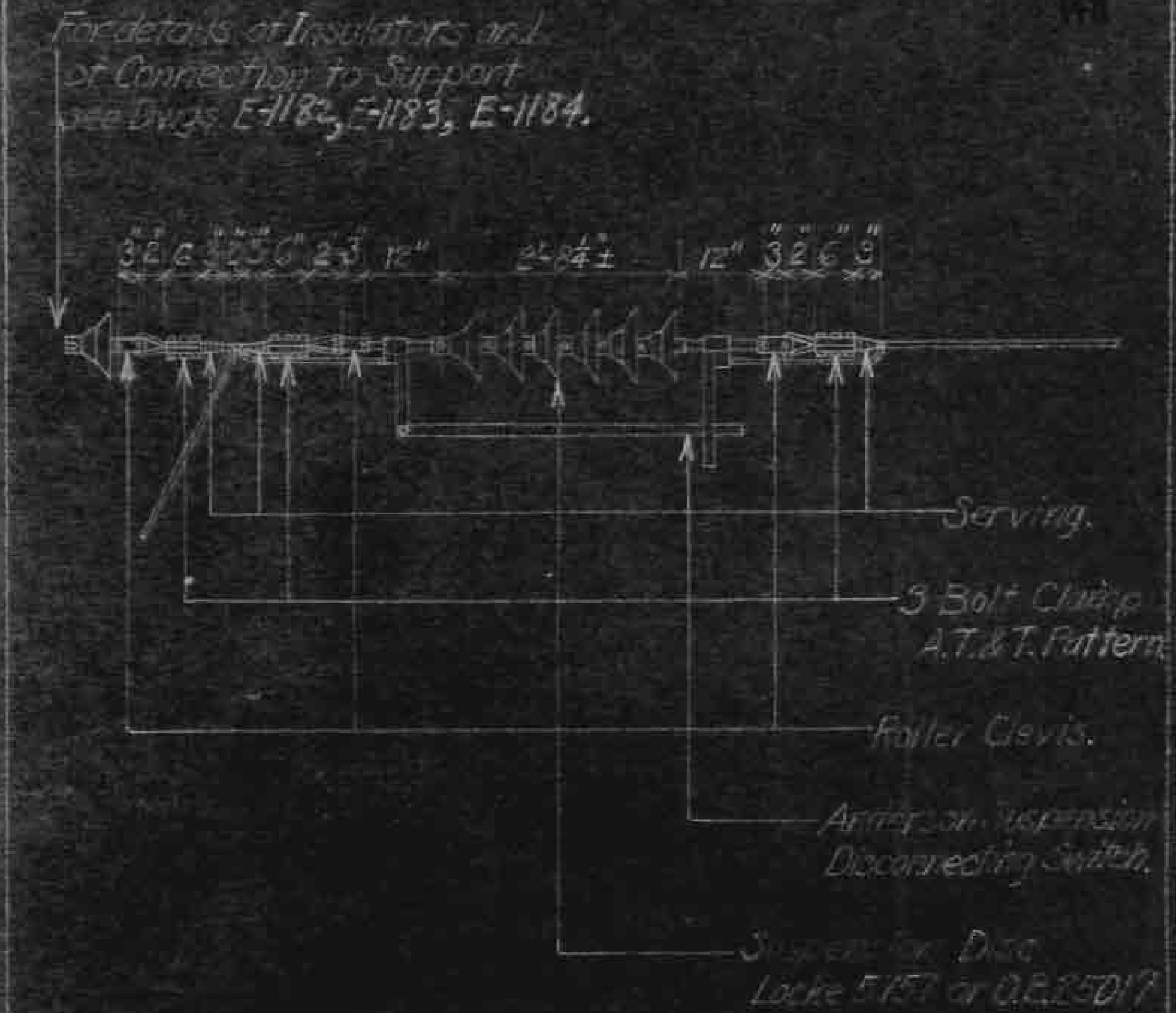


Dead End with Turn Buckle for 66000 V. Substation Bus Wiring

Notes.
1. For 110,000 Volt installations use 7 discs.
2. For 11,000 & 22000 Volt installations use 2 discs.

STANDARD BUS WIRING
SHEET NO. 13
SCALE: $\frac{1}{2}$" = 1'-0" DATE: 3-2-23
OUTDOOR SUBSTATIONS.
I. H. LOVETT.

E-1184-1

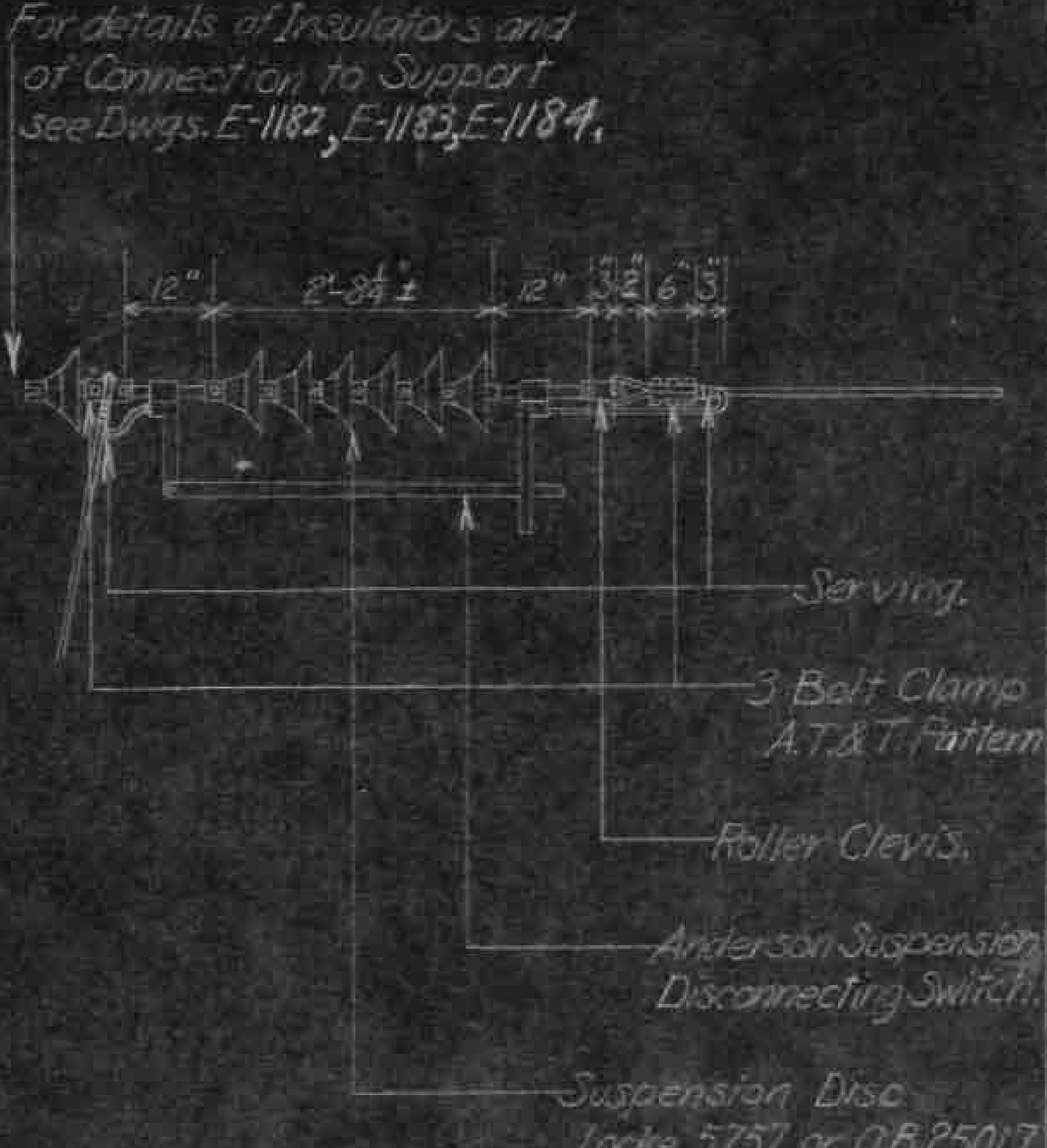


Suspension Disconnecting Switch Assembly

4

SCALE DATE 3
STATION

E-1185-1



Suspension Disconnecting Switch Assembly for 66000 V. Substation Bus Wiring.

Notes:

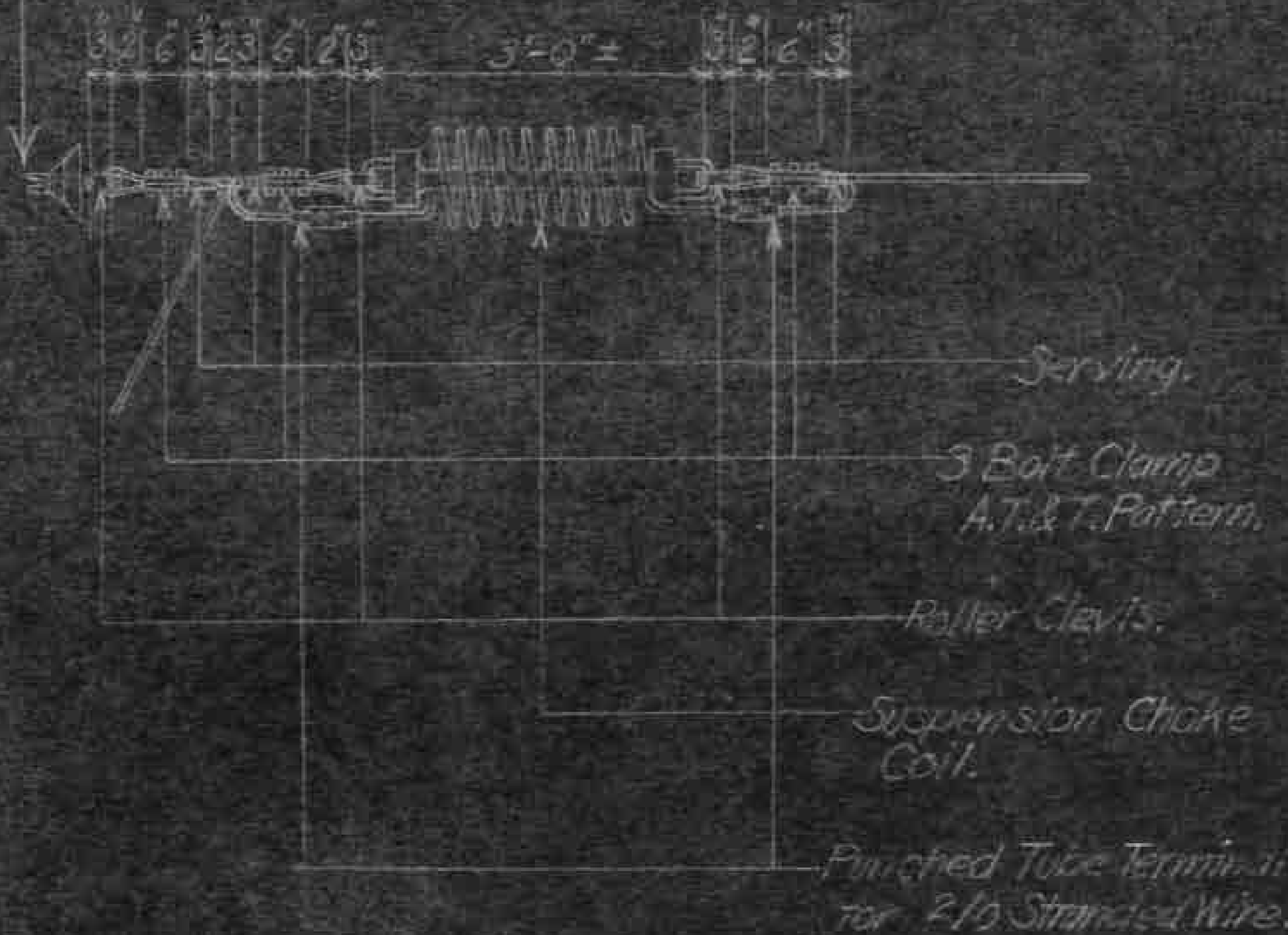
1. For 110,000 Volt installations use 7 discs.

STANDARD BUS WIRING
SHEET NO. 15

SCALE: ½"=1'-0" DATE: 6-2-23
OUTDOOR SUBSTATIONS
I.H. LOVETT.

E-1186-1

For details of Insulators and of Connection to Support see Dwgs. E-1182, E-1183, E-1184.

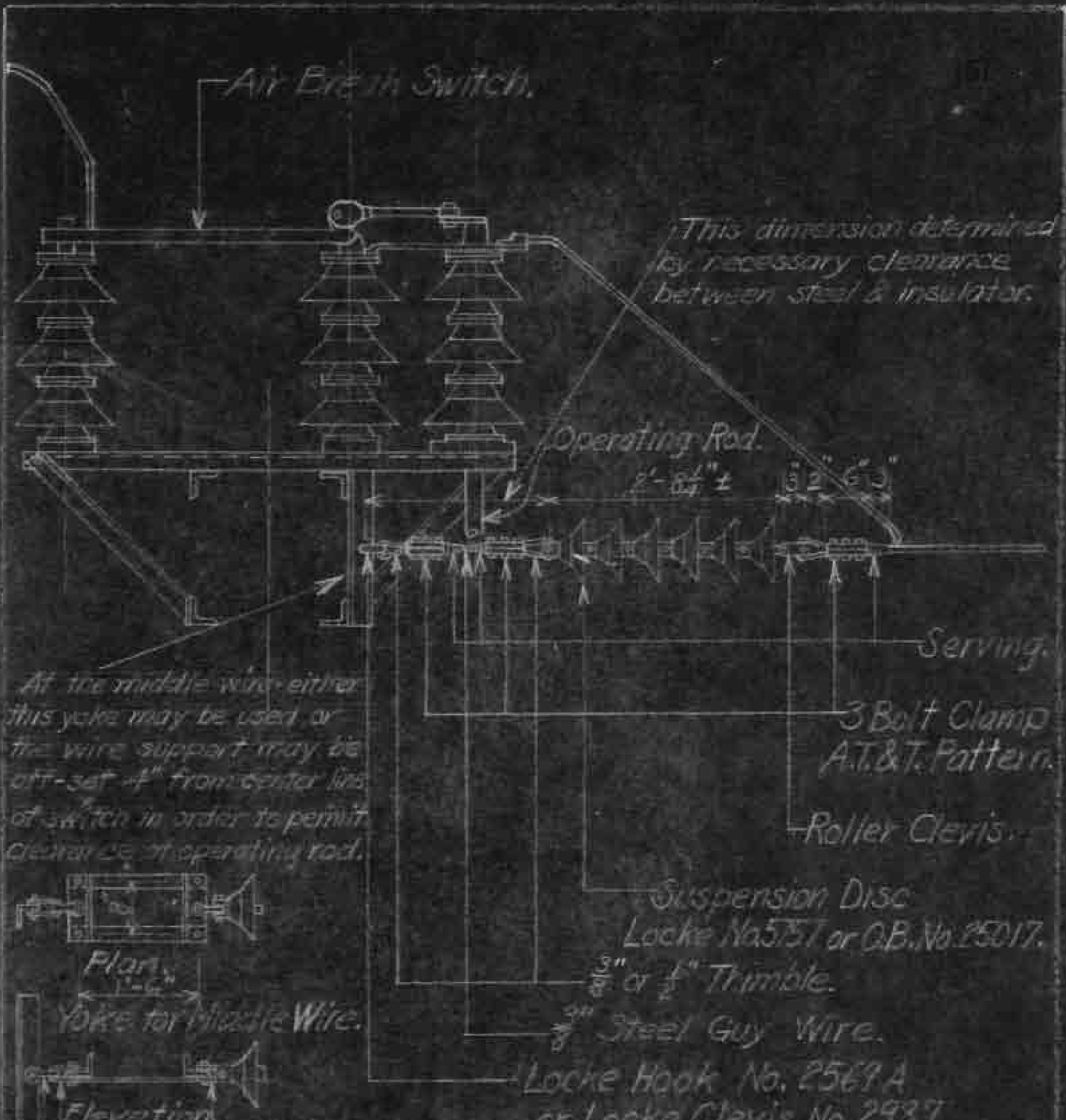


Suspension Choke Coil Assembly for 66000 V. Substation Bus Wiring.

STANDARD BUS WIRING
SHEET NO. 16

SCALE 1"=12" DATE: 3-2-23
OUTDOOR SUBSTATIONS
I.H. LOVETT.

E-1187-1



Air Break Switch Assembly for 66000 V. Substation Bus Wiring.

Notes:

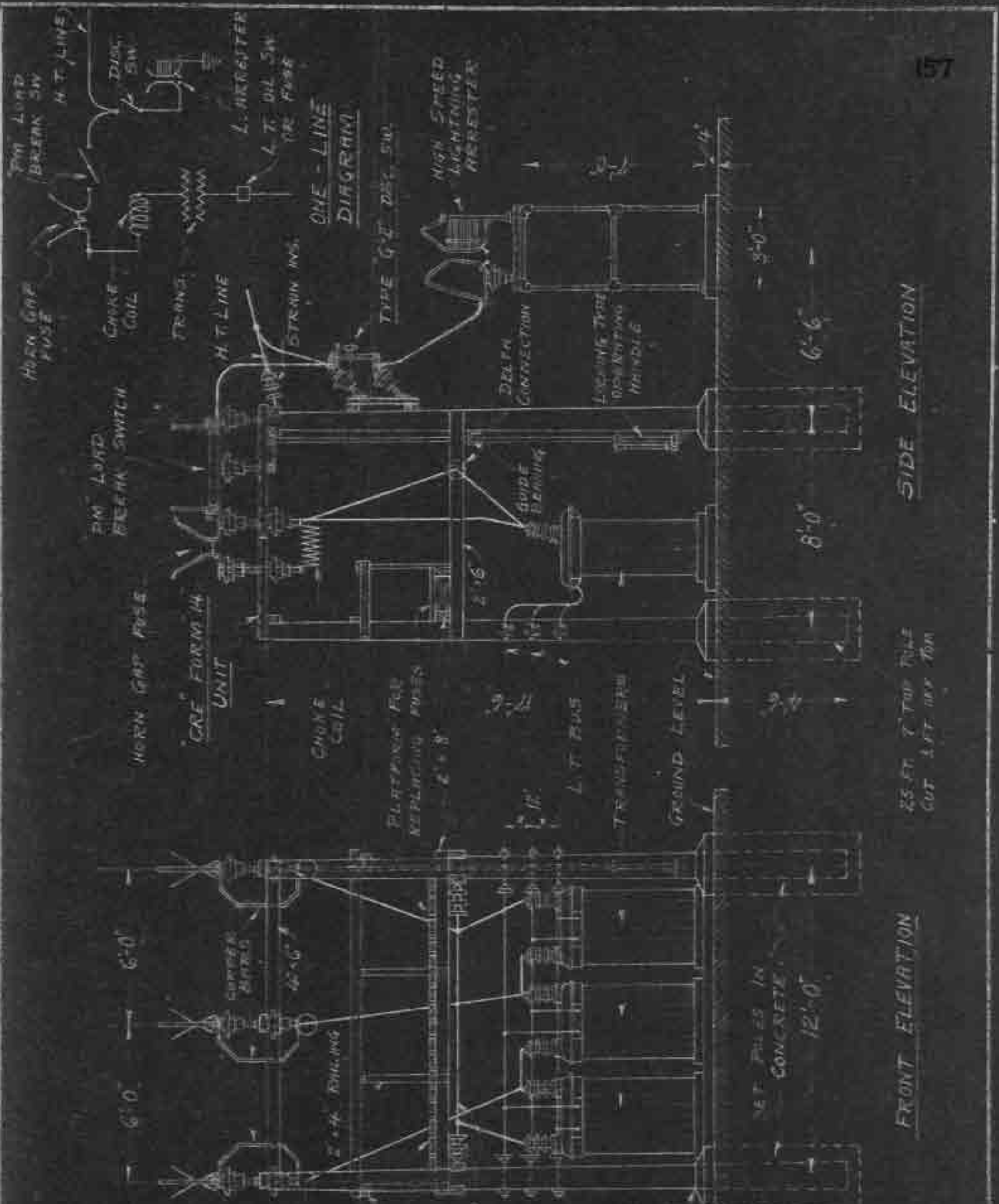
1. For 110000 Volt installations use 7 discs.

STANDARD BUS WIRING
SHEET NO. 17.

SCALE ½" = 1'-0"   DATE: 3-2-23
OUTDOOR SUBSTATIONS
I. H. LOVETT.

E-1188-1

157



Sheet No. 1

C. APPROVED:

TYPE "RL" FORM 32 SUB-STATION
FOR VOLTAGES UP TO & INCLUDING 33000 V.

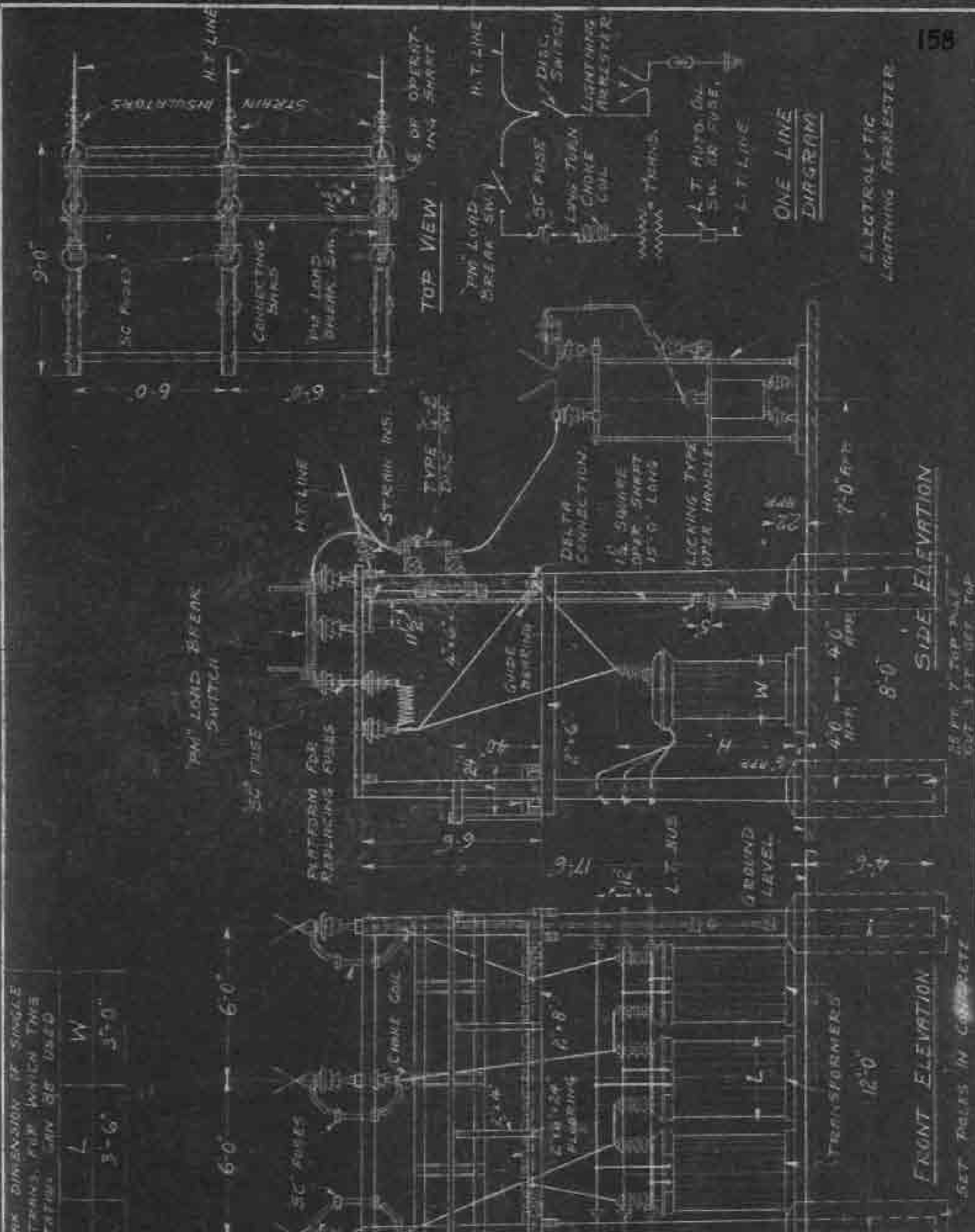
FIRST MADE FOR: STANDARD EQUIPMENT

11256

DATE: 7-1-18

PRINTS TO FILE: E-1, X, IX, X-1, D-3 M-

Form No. 41 FILE NO. 13200-W-, 22000-W-&33000-W- SUB- FILE No. A211123453



Sheet No. 2

C.

APPROVED:

TYPE "AL" FORM "33" SUB-STATION
FOR VOLTAGES UP TO & INCLUDING 33000 V.
FOR MAX. CAP. OF TRANS. SEE TABLE

FIRST MADE FOR: DOMINION GLASS CO. LIMITED MONTREAL, CANADA.

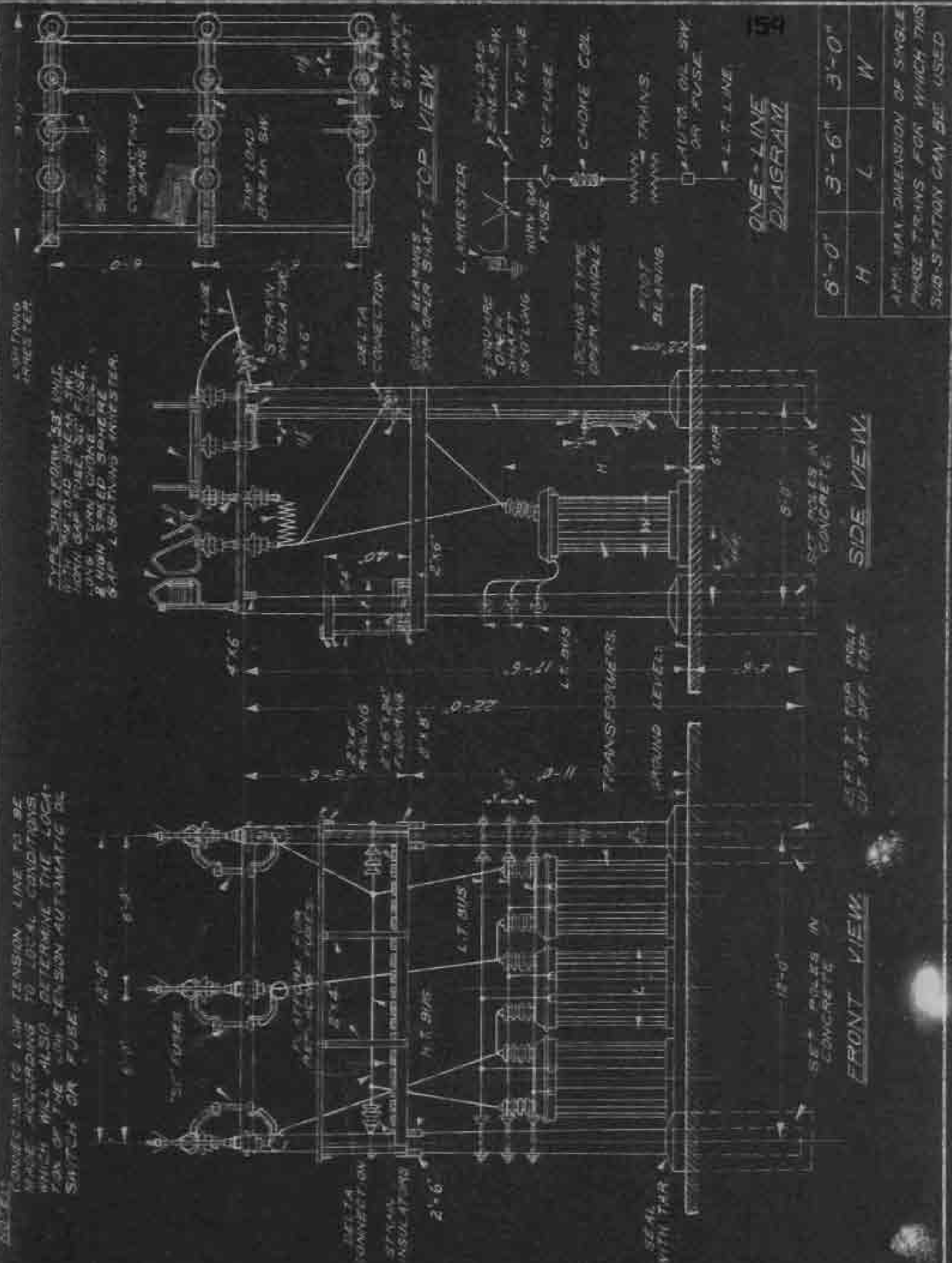
11264

DATE: 8-19-18

PRINTS TO FILE: E-1, SO, DG, N-1, D-6 M-

Form No. 41 FILE NO. 13200-W-, 22000-W- & 33000-W- SUB-FILE No. A.21.11345

159



Sheet No. 3

TYPE "AL" FORM "31D" SUB-STATION FOR VOLTAGES UP TO AND INCLUDING 33000 VOLTS.
FOR MAX. CAP. OF TRANS. SEE TABLE.
FIRST MADE FOR: STANDARD.

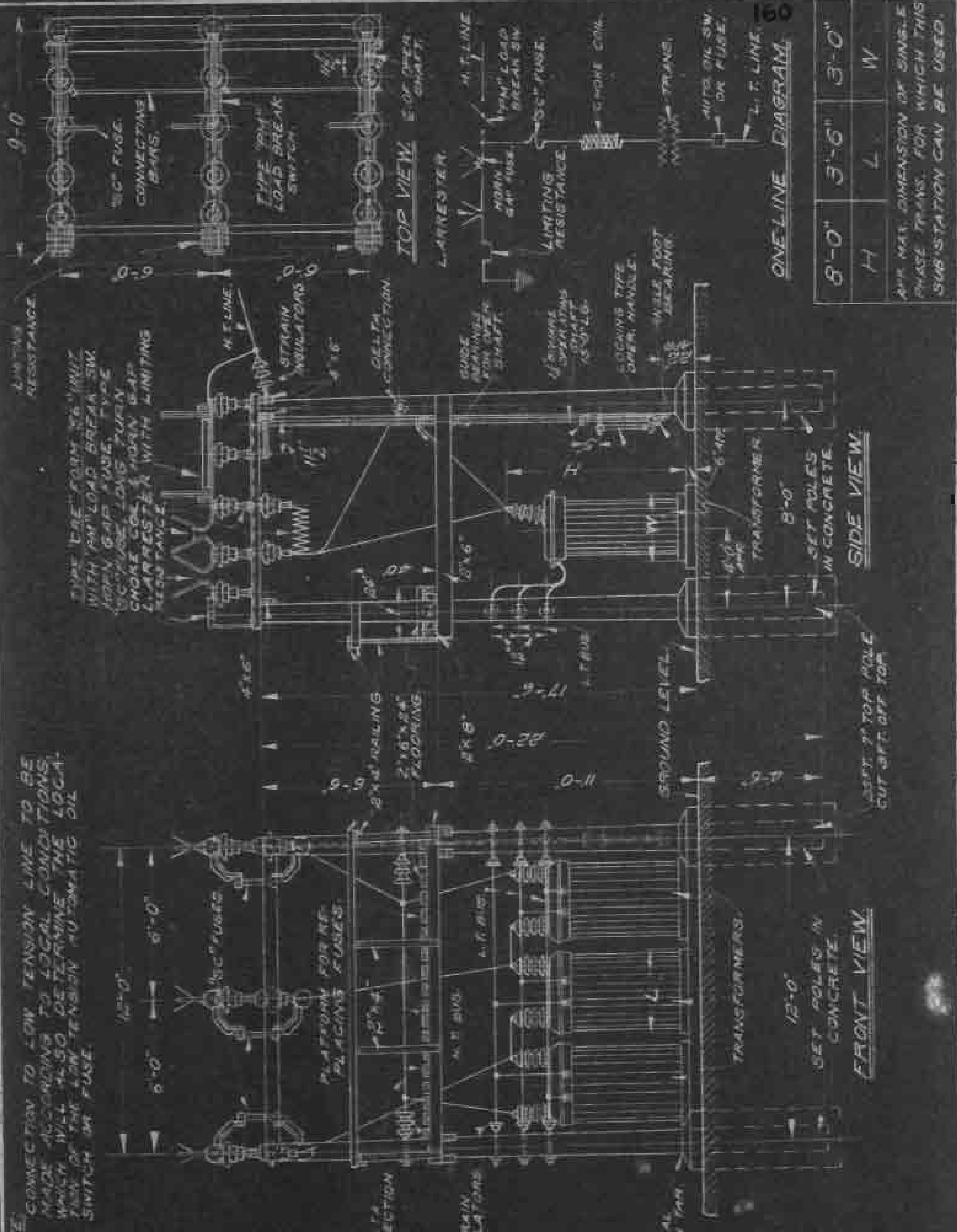
11332

DATE: 6-17-1919

PRINTED TO FILE: E-1, 104, 00, N-1, D-6.

Form No. 41 FILE NO. 13200-W-, 22000-W- & 33000-W- SUB- FILE No. A21.11345.

160



Sheet No. 4

APPROVED:

TYPE "AL" FORM "31C" SUB-STATION FOR VOLTAGES UP TO & INCLUDING 33000 VOLTS.

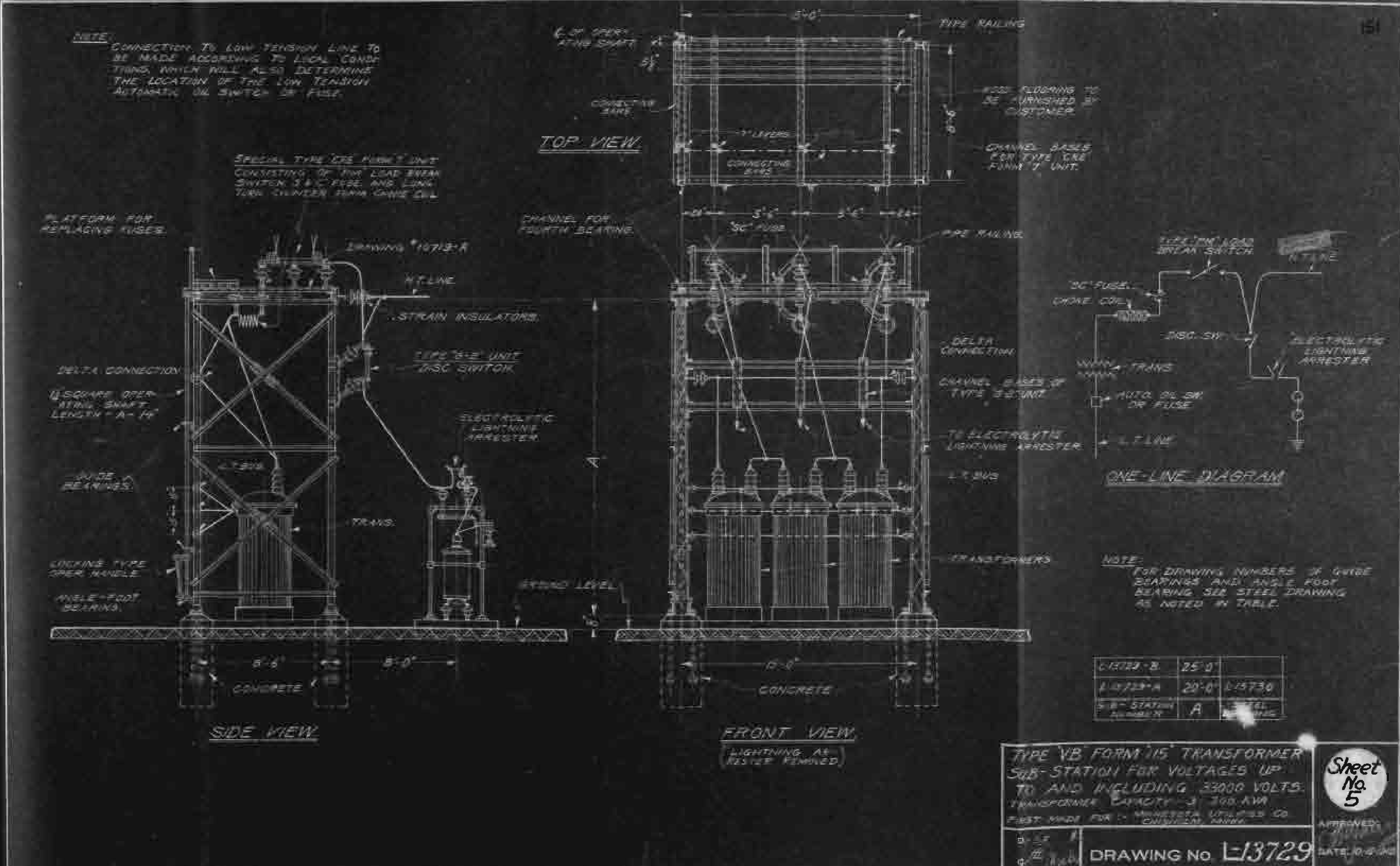
FOR MAX. CAP. OF TRANSFORMERS SEE TABLE

FIRST MADE FOR: STANDARD

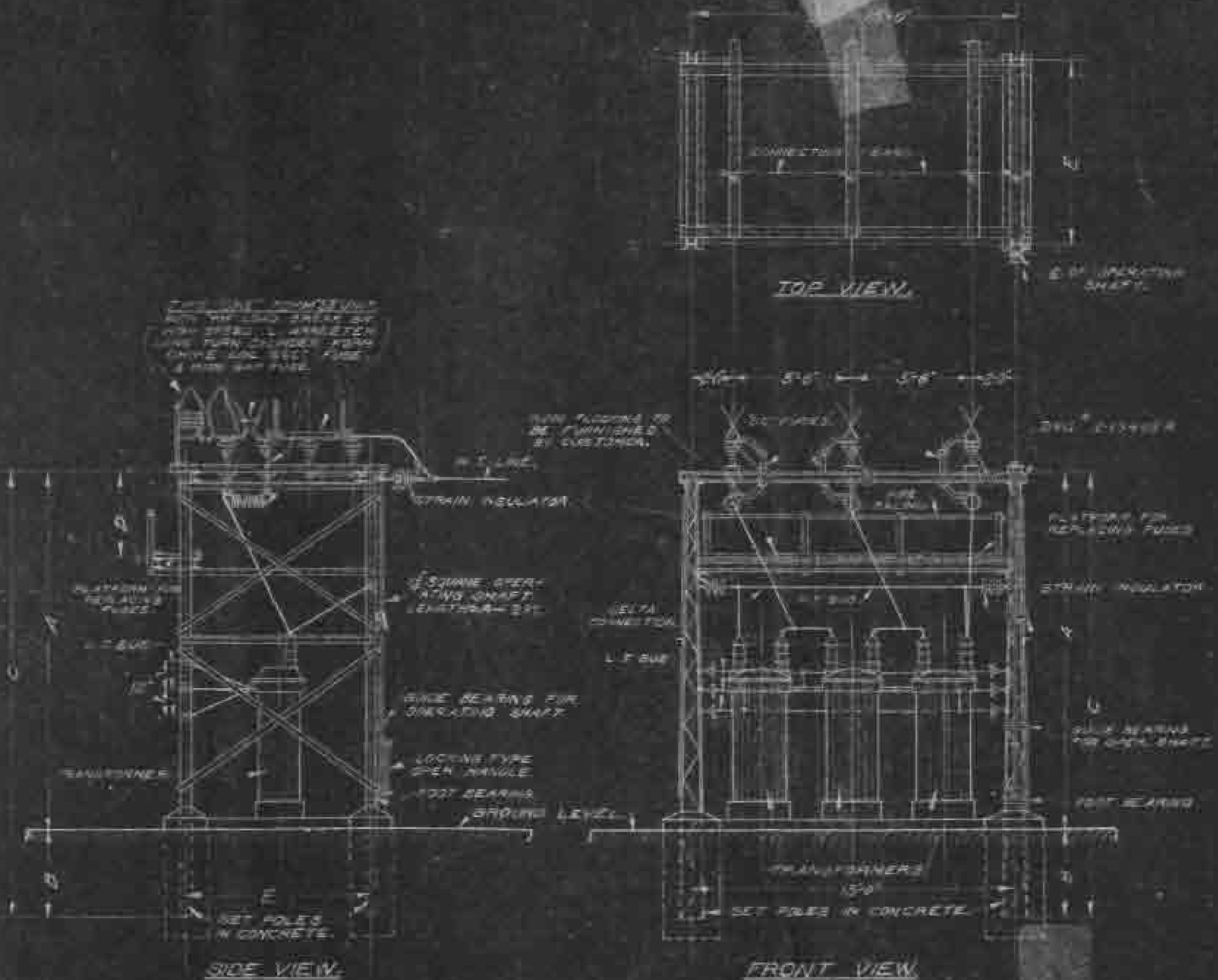
11320

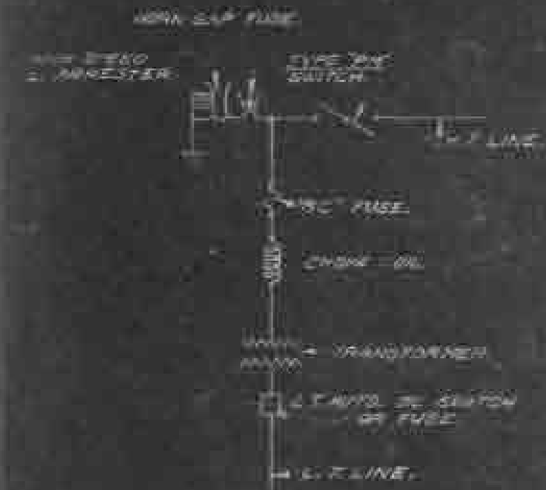
DATE: 4-18-1919.

PRINTS TO FILE: E-1, N-1, D-10,


151
NOTE:
CONNECTION TO LOW TENSION LINE TO BE MADE ACCORDING TO LOCAL CONDITIONS, WHICH WILL ALSO DETERMINE THE LOCATION OF THE LOW TENSION AUTOMATIC OIL SWITCH OR FUSE.
SPECIAL TYPE "CRE" FORM 7 UNIT
CONSISTING OF "PM" LOAD BREAK SWITCH, 3 & C FUSE AND LONG TURN CYLINDER FORM CHOKE COIL
PLATFORM FOR REPLACING FUSES.
DRAWING 10713-A
H.T. LINE
STRAIN INSULATORS
TYPE "S-2" UNIT DISC SWITCH
DELTA CONNECTION
SQUARE OPERATING SHAFT LENGTH "A" 14"
ELECTROLYTIC LIGHTNING ARRESTER
L.T. BUS
GUIDE BEARINGS
TRANS.
LOCKING TYPE OPER. HANDLE
ANGLE-FOOT BEARING
GROUND LEVEL
6'-6"
8'-0"
CONCRETE
SIDE VIEW
TOP VIEW
5'-0"
PIPE RAILING
CONNECTING BARS
LEVERS
CONNECTING BARS
WOOD FLOORING TO BE FURNISHED BY CUSTOMER
CHANNEL BASES FOR TYPE "CRE" FORM 7 UNIT
CHANNEL FOR FOURTH BEARING
3'-6"
3'-6"
"SC" FUSE
PIPE RAILING
DELTA CONNECTION
CHANNEL BASES OF TYPE S-2 UNIT
TO ELECTROLYTIC LIGHTNING ARRESTER
L.T. BUS
TRANSFORMERS
10'-0"
CONCRETE
FRONT VIEW
(LIGHTNING ARRESTER REMOVED)
TYPE "PM" LOAD BREAK SWITCH
H.T. LINE
"SC" FUSE
CHOKE COIL
DISC. SW.
ELECTROLYTIC LIGHTNING ARRESTER
TRANS.
AUTO. OIL SW. OR FUSE
L.T. LINE
ONE-LINE DIAGRAM
NOTE:
FOR DRAWING NUMBERS OF GUIDE BEARINGS AND ANGLE FOOT BEARING SEE STEEL DRAWING AS NOTED IN TABLE.
L-13729-B | 25'-0"
L-13729-A | 20'-0" | L-13730
SUB-STATION NUMBER | A | STEEL DRAWING
TYPE VB FORM 115 TRANSFORMER SUB-STATION FOR VOLTAGES UP TO AND INCLUDING 33000 VOLTS.
TRANSFORMER CAPACITY 3-300 KW
FIRST MADE FOR :- MINNESOTA UTILITIES CO. CHISHOLM, MINN.
Sheet No. 5
APPROVED
DRAWING No. L-13729
DATE 10-6-20

NOTE:
CONNECTION TO LOW TENSION LINE TO BE MADE ACCORDING TO LOCAL CONDITIONS WHICH WILL ALSO DETERMINE THE LOCATION OF THE LOW TENSION AUTOMATIC OIL SWITCH OR FUSE.





ONE LINE DIAGRAM.

L-13535-C	22'-0"	5'-0"	30'-0"	7'-0"	7'-6	
L-13535-B	20'-0"	5'-0"	25'-0"	7'-0"	5'-5	L-13571
L-13535-A	16'-6"	3'-6"	20'-0"	4'-0"	3'-5	
SUB-STATION NUMBER	A	B	C	D	E	STEEL DWG. NO.

NOTE:
FOR DRAWING NUMBERS OF GUIDE BEARINGS, FOOT BEARING, AND BASE OF "SPS" UNITS SEE STEEL DRAWING AS NOTED IN TABLE.

TYPE "VB" FORM "Y4" TRANSFORMER SUB-STATION FOR VOLTAGES UP TO AND INCLUDING 33000 VOLTS
TRANS. CAP. 3-200 K.V.A.
FIRST MADE FOR: STANDARD.

Sheet No. 6

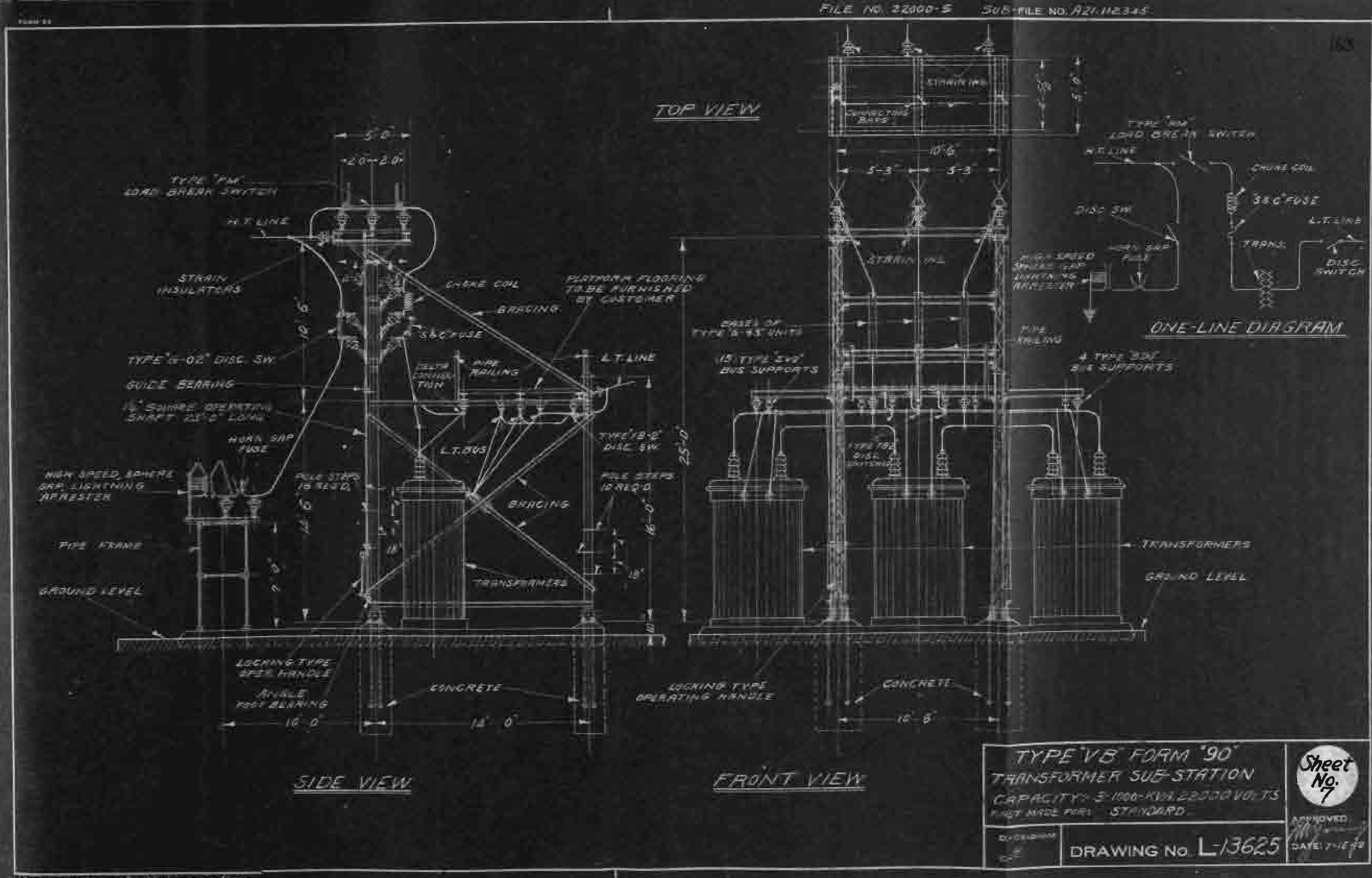
APPROVED:

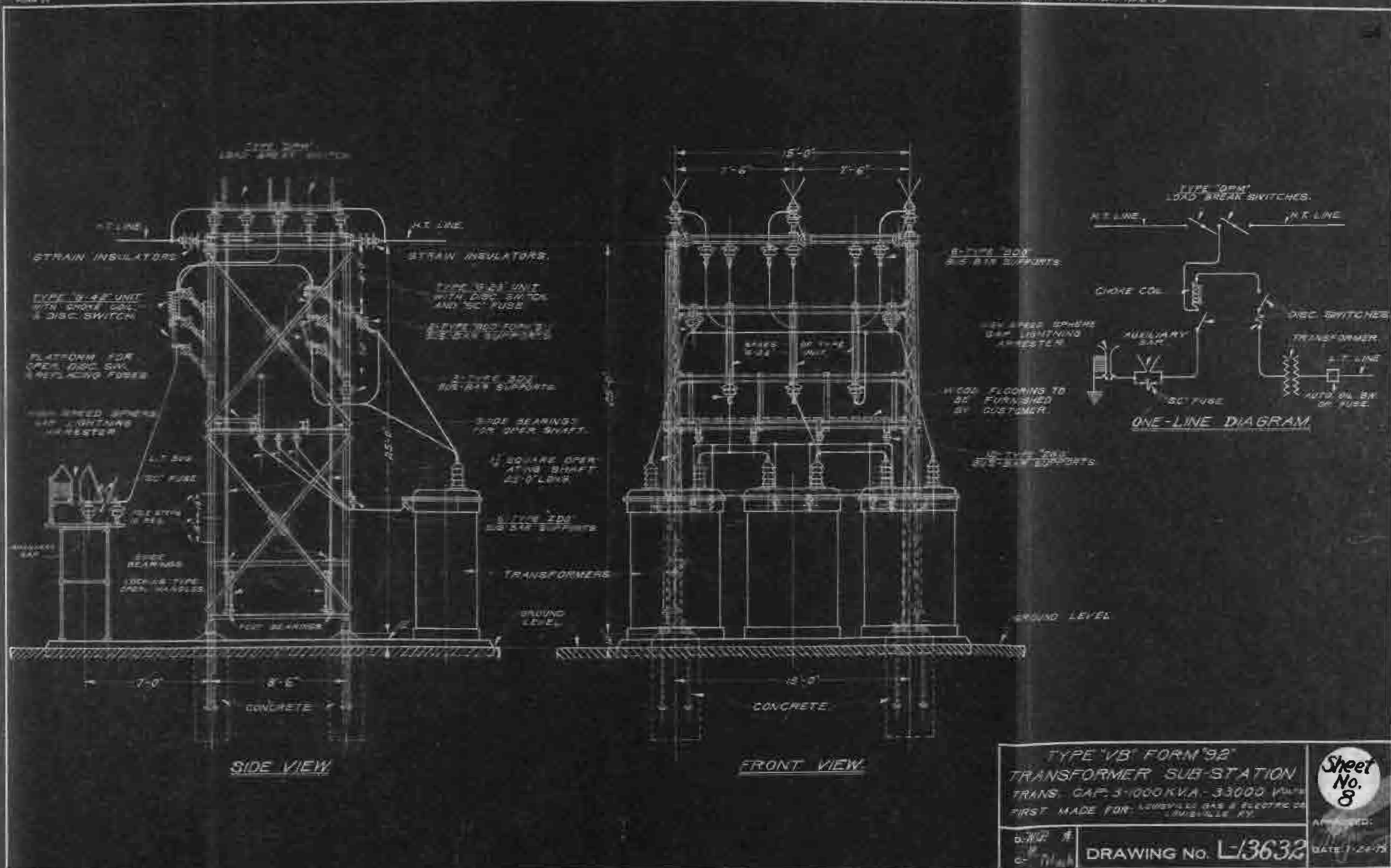
DRAWING No. L-13535

DATE: 3-15-1919

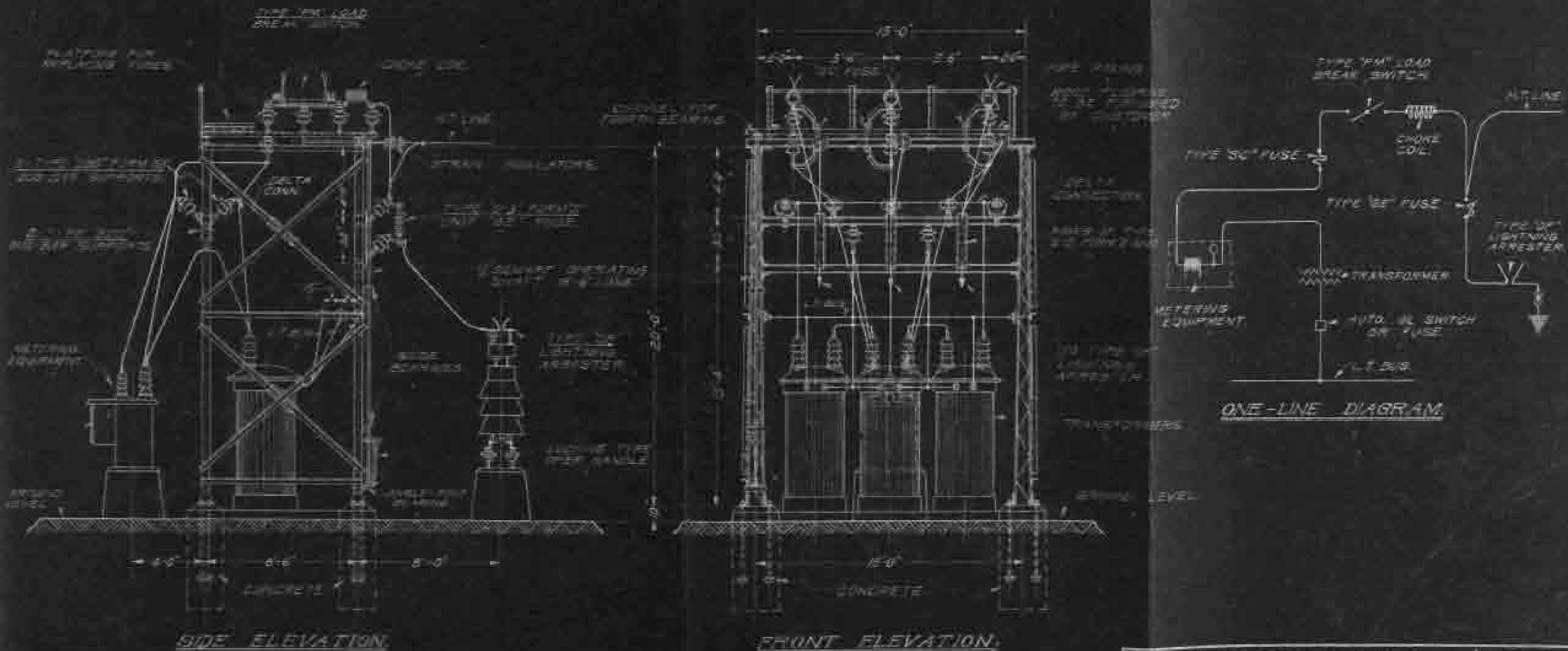
REVISED 5-14-19

PRINTS TO FILE: E.S. SO. W. N.L. D.S. M.


FILE NO. 22000-S SUB-FILE NO. A21.112345
TOP VIEW
STRAIN INS.
CONNECTING BARS
10'-6"
5'-3" 5'-3"
5'-0"
2'-0" 2'-0"
TYPE "PM" LOAD BREAK SWITCH
H.T. LINE
STRAIN INSULATORS
CHOKE COIL
BRACING
PLATFORM FLOORING TO BE FURNISHED BY CUSTOMER
S&C FUSE
TYPE "G-02" DISC. SW.
PIPE RAILING
L.T. LINE
GUIDE BEARING
1½" SQUARE OPERATING SHAFT 22'-0" LONG
HORN GAP FUSE
L.T. BUS
TYPE "B-2" DISC. SW.
HIGH SPEED SPHERE GAP LIGHTNING ARRESTER
POLE STEPS 16 REQ'D.
POLE STEPS 10 REQ'D.
BRACING
PIPE FRAME
TRANSFORMERS
GROUND LEVEL
LOCKING TYPE OPER. HANDLE
ANGLE FOOT BEARING
CONCRETE
16'-0"
14'-0"
25'-0"
10'-6"
16'-0"
SIDE VIEW
STRAIN INS.
BASES OF TYPE "A-43" UNITS
15 TYPE "SW" BUS SUPPORTS
4 TYPE "SW" BUS SUPPORTS
PIPE RAILING
TRANSFORMERS
GROUND LEVEL
LOCKING TYPE OPERATING HANDLE
CONCRETE
10'-6"
FRONT VIEW
TYPE "AM" LOAD BREAK SWITCH
H.T. LINE
CHOKE COIL
S&C FUSE
DISC SW.
L.T. LINE
HIGH SPEED SPHERE GAP LIGHTNING ARRESTER
HORN GAP FUSE
TRANS.
DISC SWITCH
ONE-LINE DIAGRAM
TYPE "V.B" FORM "90"
TRANSFORMER SUB-STATION
CAPACITY: 3-1000-KVA 22000 VOLTS
FIRST MADE FOR: STANDARD
DRAWING No. L-13625
Sheet No. 7
APPROVED



FILE NO. 33000-S
SUB-FILE NO.
H.T. LINE
STRAIN INSULATORS
STRAIN INSULATORS
TYPE "G-42" UNIT WITH CHOKE COIL & DISC. SWITCH
PLATFORM FOR OPER. DISC. SW. & REPLACING FUSES
HIGH SPEED SPHERE GAP LIGHTNING ARRESTER
TRANSFORMERS
GROUND LEVEL
CONCRETE
7'-0"
8'-6"
SIDE VIEW
15'-0"
7'-6"
7'-6"
CONCRETE
FRONT VIEW
GROUND LEVEL
WOOD FLOORING TO BE FURNISHED BY CUSTOMER
TYPE "OPM" LOAD BREAK SWITCHES.
H.T. LINE
CHOKE COIL
DISC. SWITCHES
AUXILIARY GAP
TRANSFORMER
"SC" FUSE
AUTO. OIL SW. OR FUSE
ONE-LINE DIAGRAM
TYPE "VB" FORM "92"
TRANSFORMER SUB-STATION
TRANS. CAP. 3-1000 K.V.A. - 33000 Volts
FIRST MADE FOR: LOUISVILLE GAS & ELECTRIC CO. LOUISVILLE KY.
Sheet No. 8
DRAWING No. L-13632



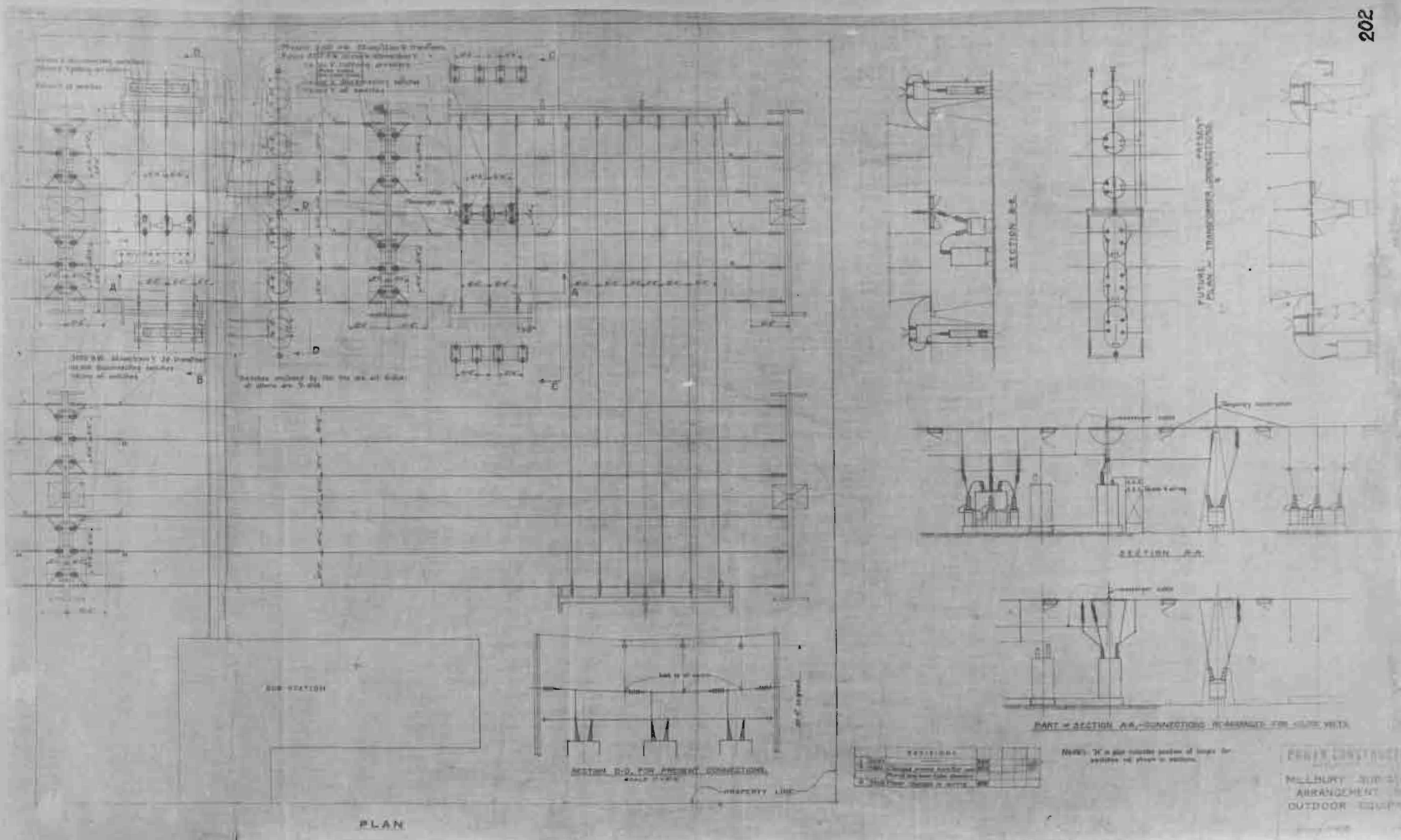
TYPE "VB" FORM "110"
TRANSFORMER SUB-STATION
TRANS. CAP. 3-200 K.V.A. 33000 V.
FIRST MADE FOR: STANDARD

DRAWING No. L-13706

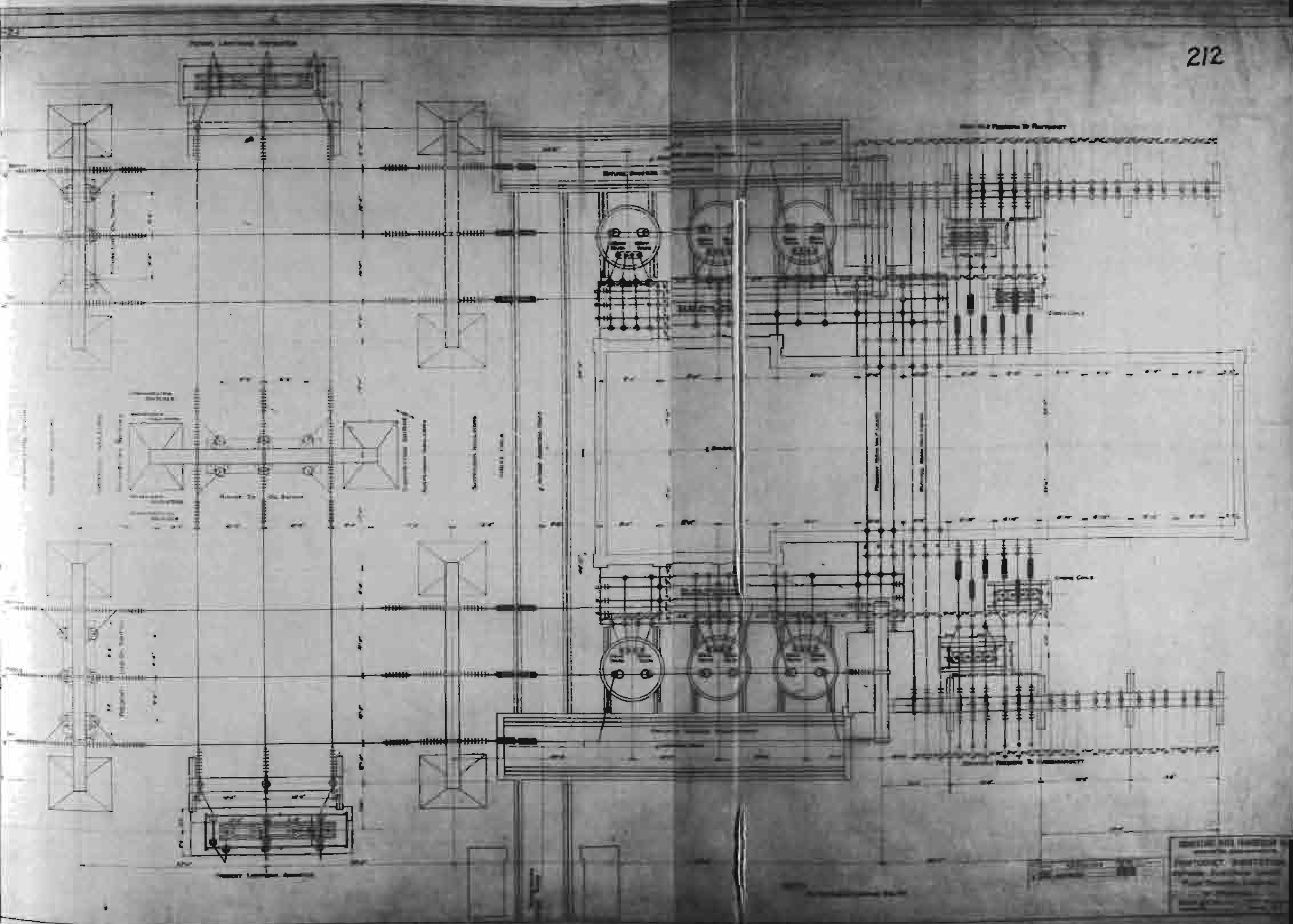
Sheet No. 9

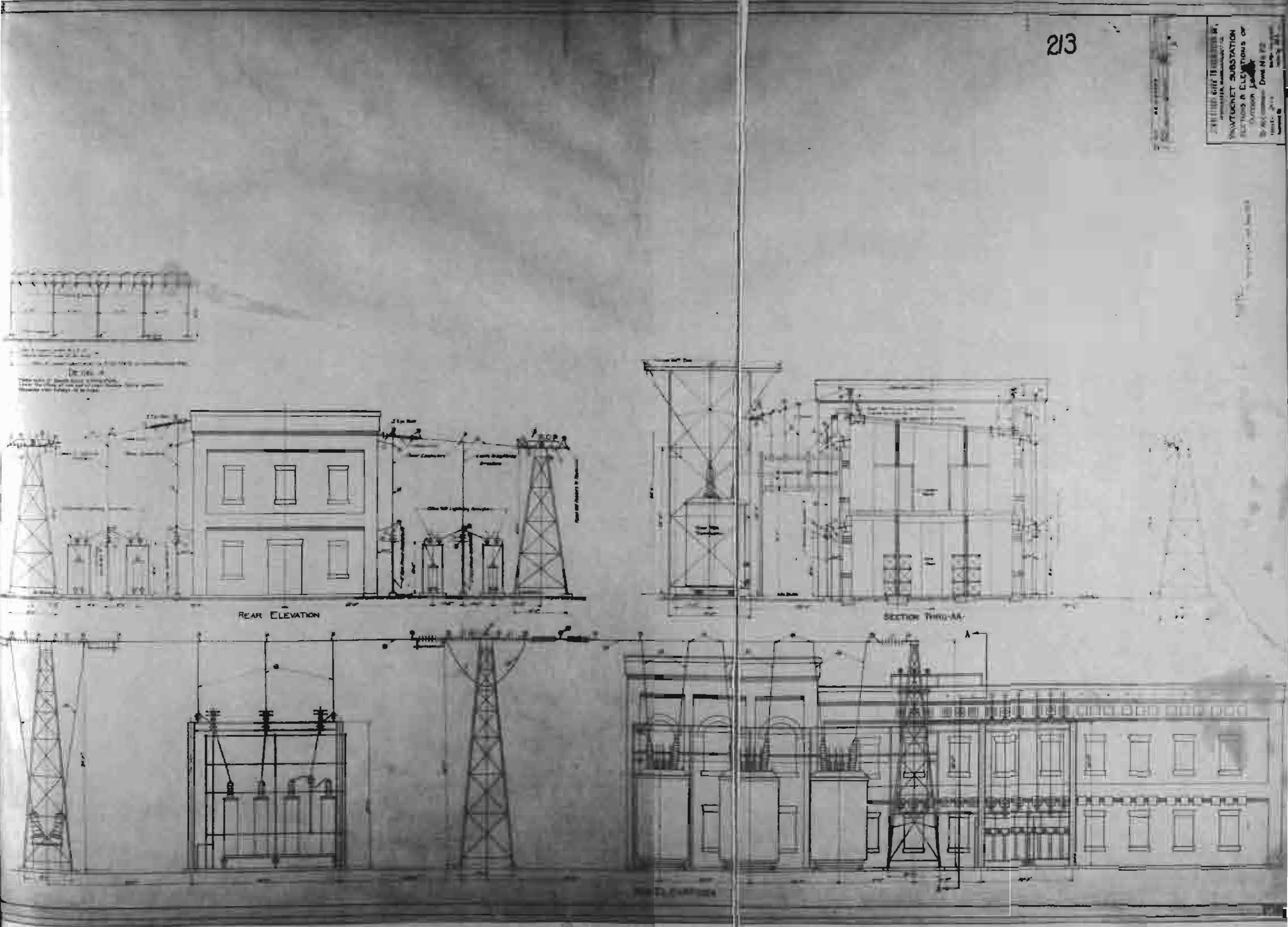
APPROVED:

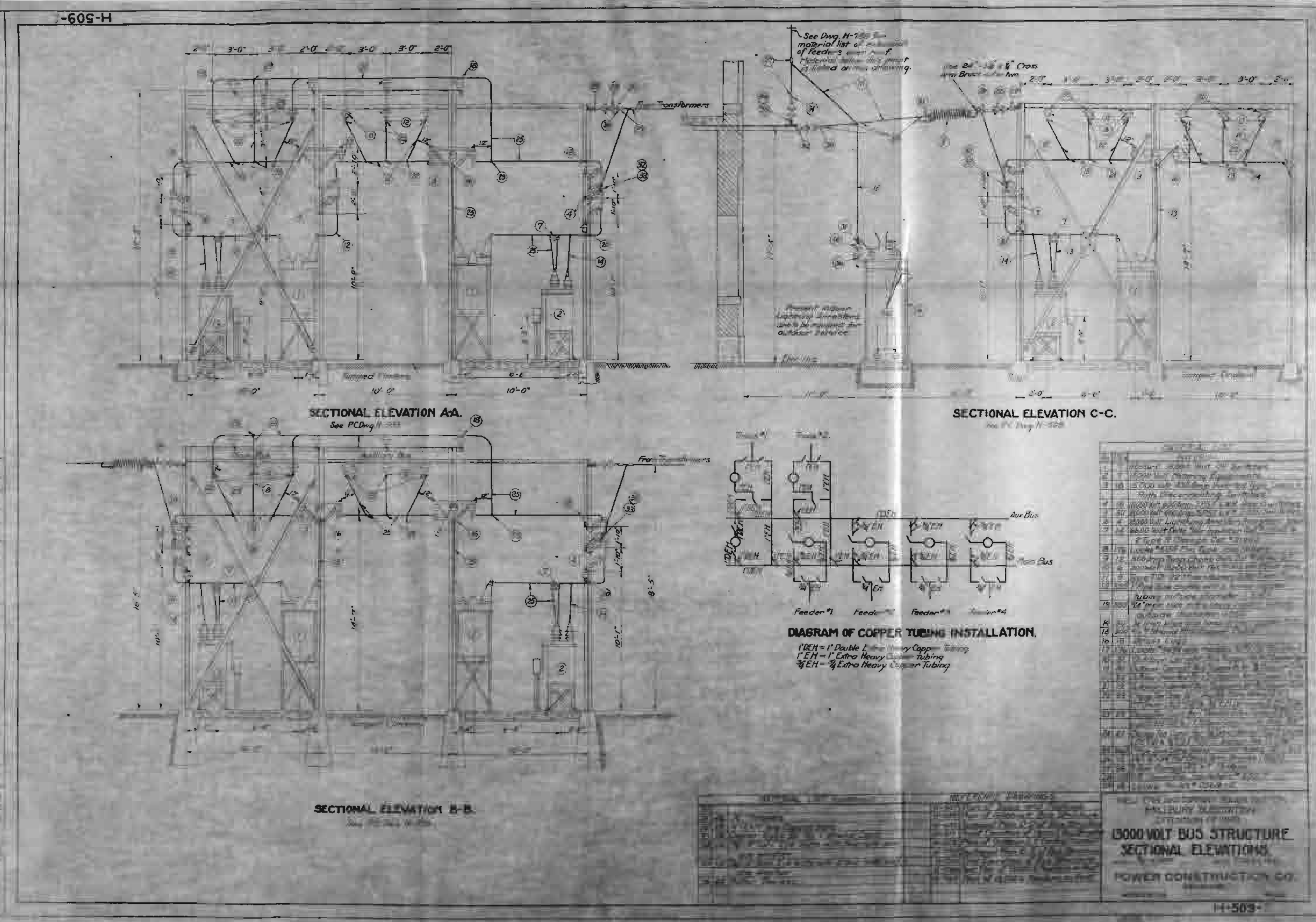
DATE:


PLAN
SUB STATION
SECTION B-B
SECTION A-A
SECTION D-D FOR PRESENT CONNECTIONS
PROPERTY LINE
FUTURE
PRESENT
PLAN - TRANSFORMER CONNECTIONS
REVISIONS
ARRANGEMENT
OUTDOOR

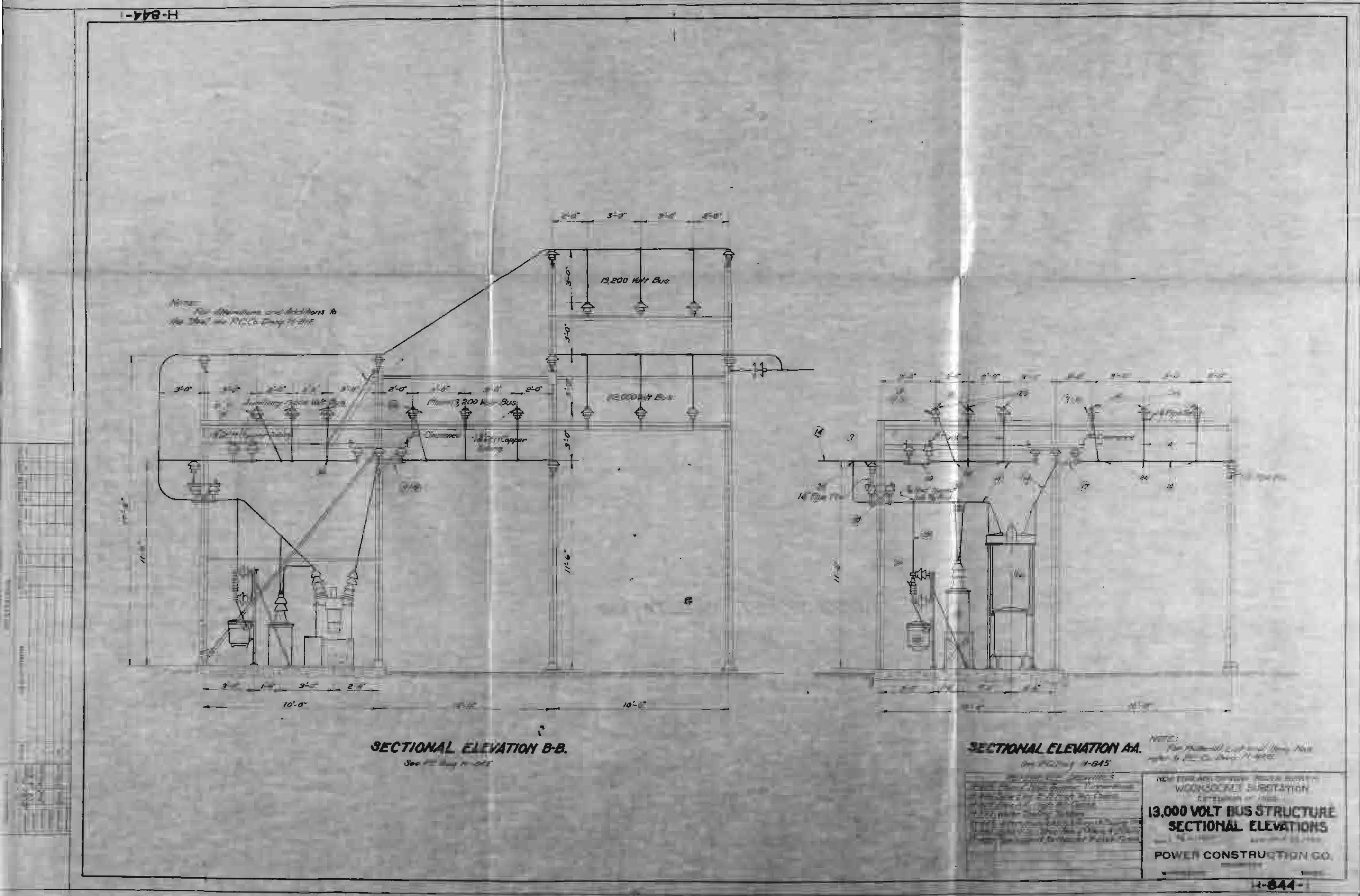
202

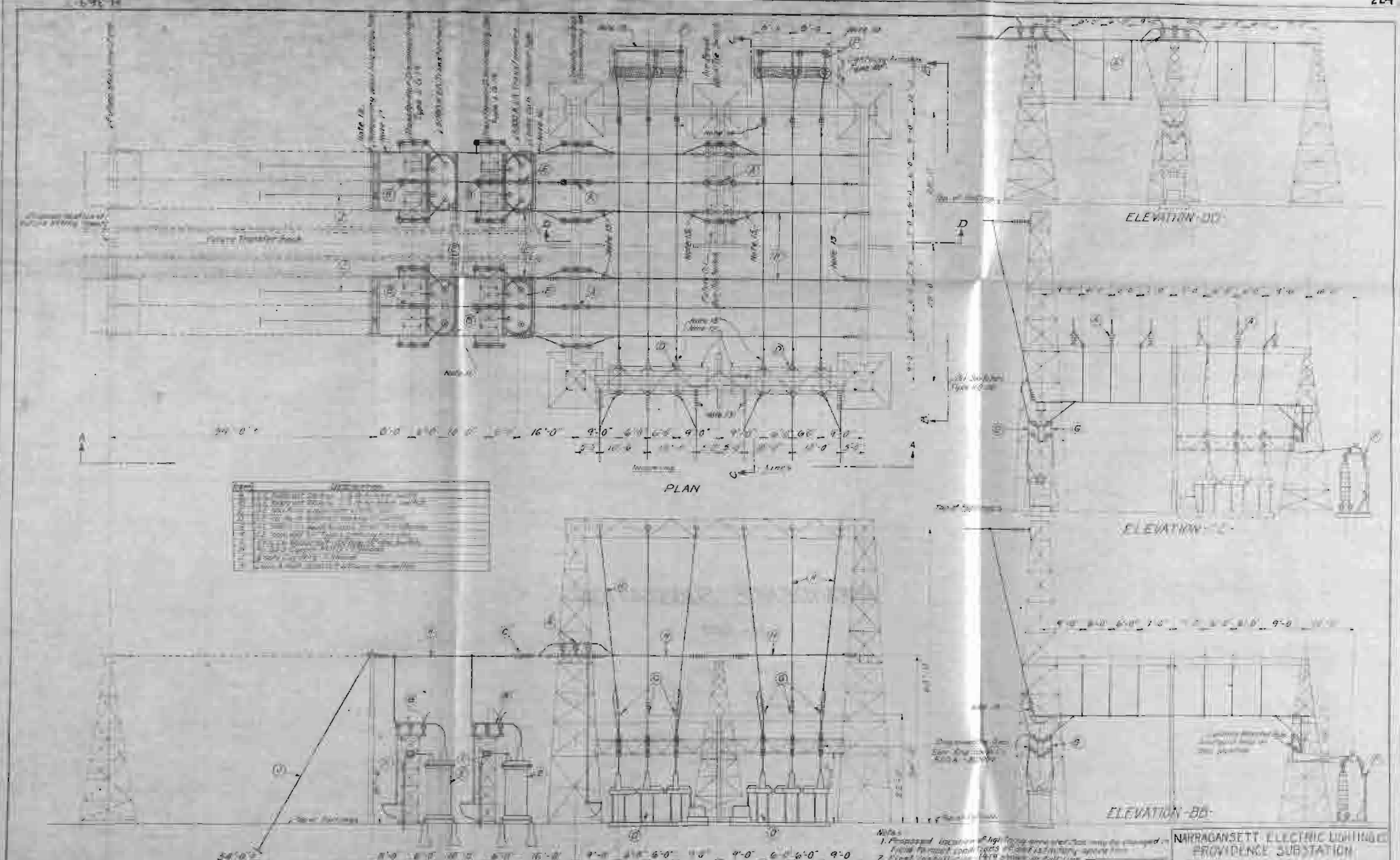



213
PAWTUCKET SUBSTATION
SECTIONS & ELEVATIONS OF
OUTDOOR
DWG No F2
DETAIL A
REAR ELEVATION
SECTION THRU-AA
A



H-509-
See Dwg. H-... for material list of ... of Feeders ...
From Transformers
SECTIONAL ELEVATION A-A.
See PC Dwg. H-...
SECTIONAL ELEVATION C-C.
SECTIONAL ELEVATION B-B.
Aux Bus
Main Bus
Feeder #1
Feeder #2
Feeder #3
Feeder #4
DIAGRAM OF COPPER TUBING INSTALLATION.
1" DEH = 1" Double Extra Heavy Copper Tubing
1" EH = 1" Extra Heavy Copper Tubing
3/4" EH = 3/4" Extra Heavy Copper Tubing
13000 VOLT BUS STRUCTURE
SECTIONAL ELEVATIONS
POWER CONSTRUCTION CO.
H-503-


H-844-1
19,200 Volt Bus
Auxiliary 13,200 Volt Bus
Main 13,200 Volt Bus
13,200 Volt Bus
SECTIONAL ELEVATION B-B.
SECTIONAL ELEVATION A-A.
1-845
WOONSOCKET SUBSTATION
13,000 VOLT BUS STRUCTURE
SECTIONAL ELEVATIONS
POWER CONSTRUCTION CO.
H-844-1



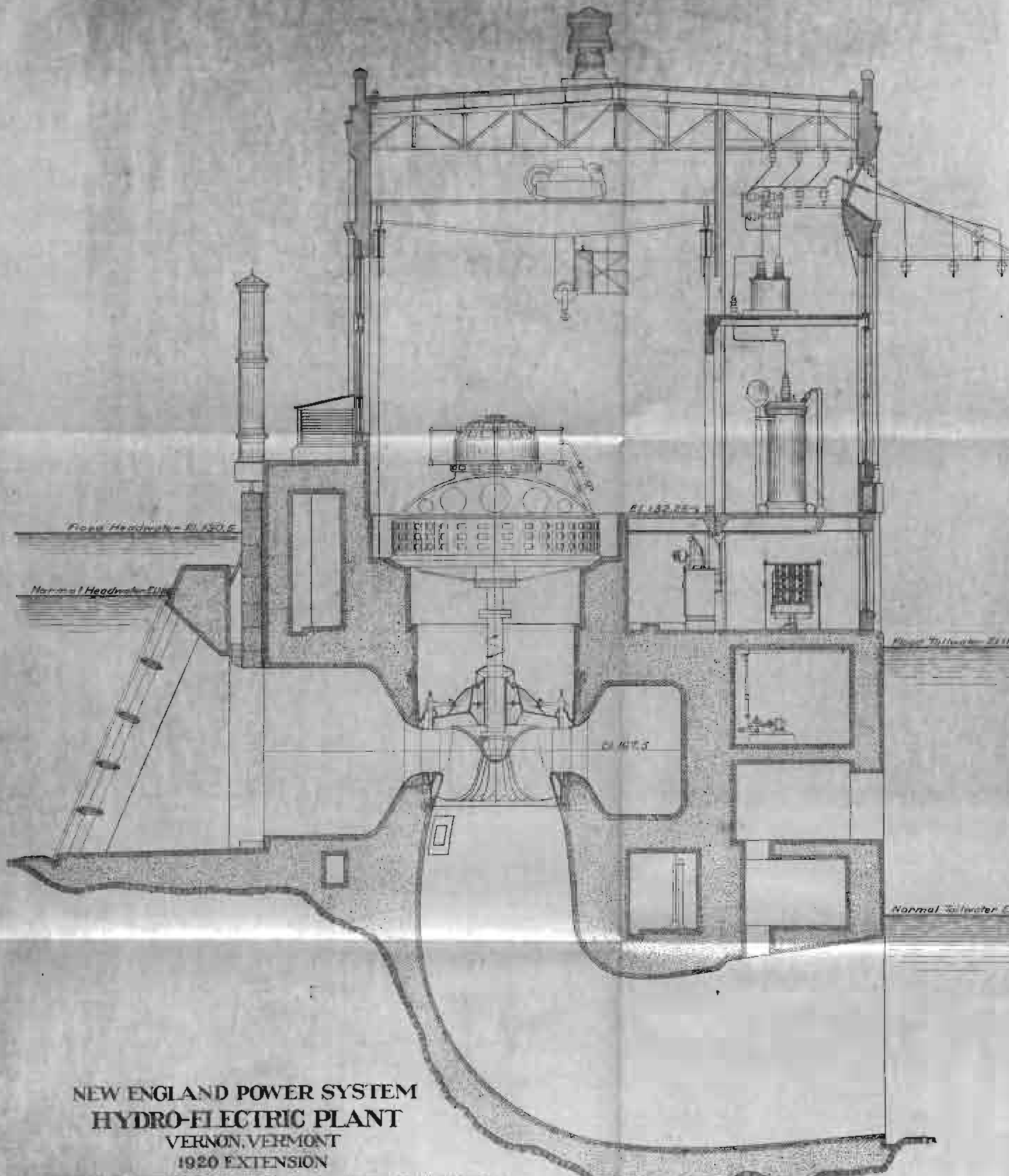
REFERENCE DRAWINGS		
Note No.	Dwg. No.	Description
10	E-75[illegible]	Foundation for Type [illegible] Lightning Arrester
[illegible]	E-79[illegible]	Foundation for Transformers.
[illegible]	E-791-	Foundation for H O 3[illegible] Oil Switch
[illegible]	E-745-	[illegible] Bus Wiring - Dead End
[illegible]	[illegible]	[illegible] Dead End with [illegible]
[illegible]	[illegible]	[illegible] Air Break [illegible]

REFERENCE DRAWINGS		
Note No.	Dwg. No.	Description
16	E-748	[illegible] Bus Wiring - Dead End [illegible]
17	E-73[illegible]	[illegible] Dead End Detail "F"
18	E-73[illegible]	Detail of Steel [illegible] and
19	H-372	[illegible] outdoor [illegible]

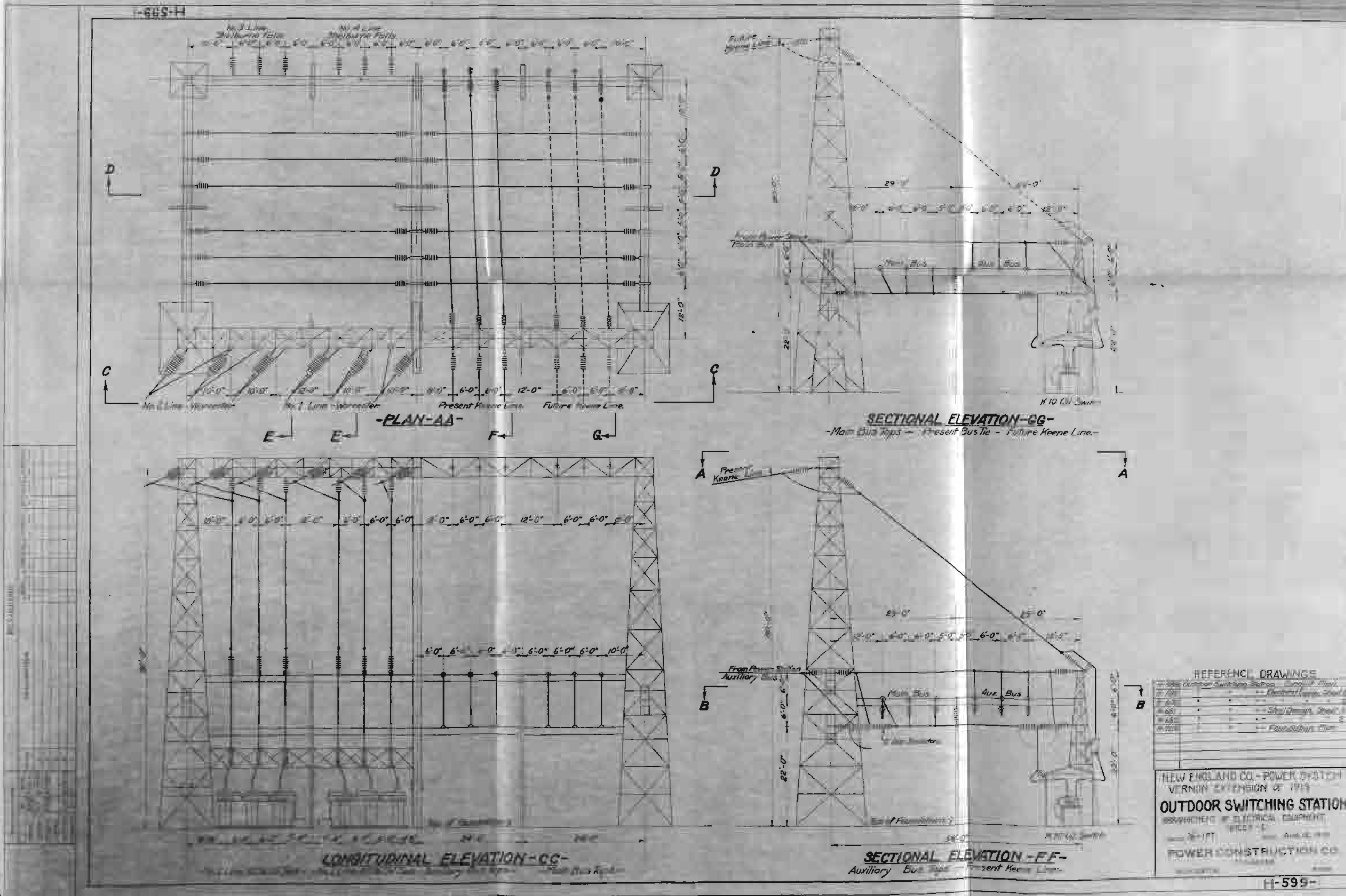
Notes.
1. Proposed location of lightning arrester [illegible] may be changed. [illegible]
2. First installation [illegible] shown in full line.
Future installation [illegible] shown in dotted line.

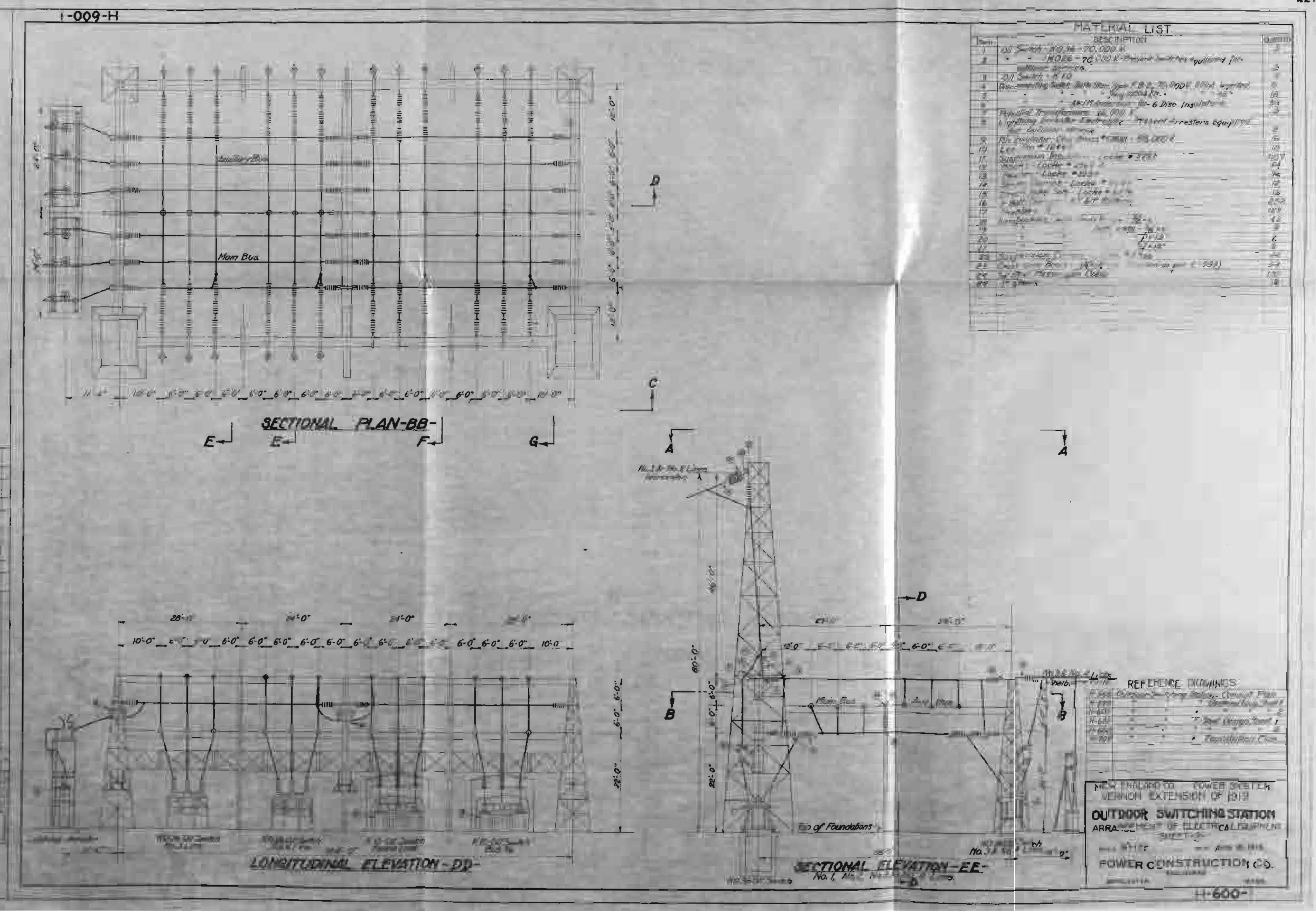
NARRAGANSETT ELECTRIC LIGHTING CO.
PROVIDENCE SUBSTATION
PLAN & ELEVATIONS SHOWING GENERAL LAYOUT
POWER CONSTRUCTION CO.
WORCESTER, MASS.

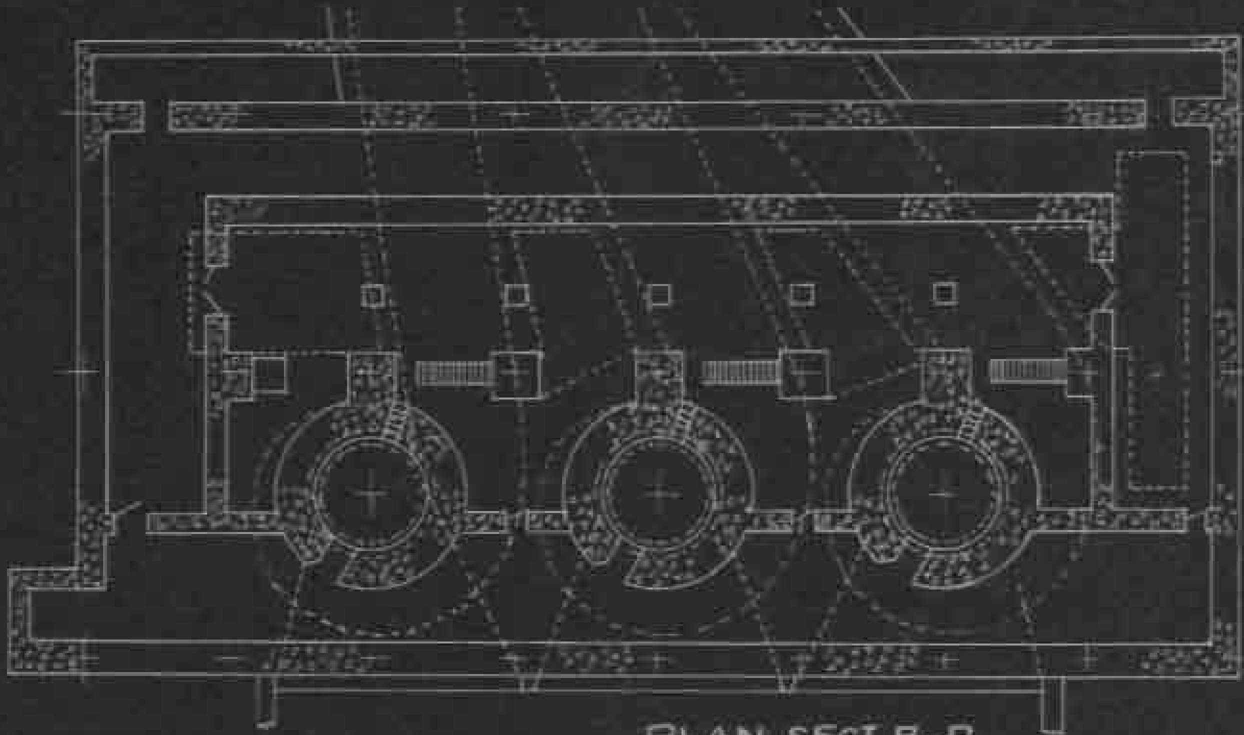
H-369



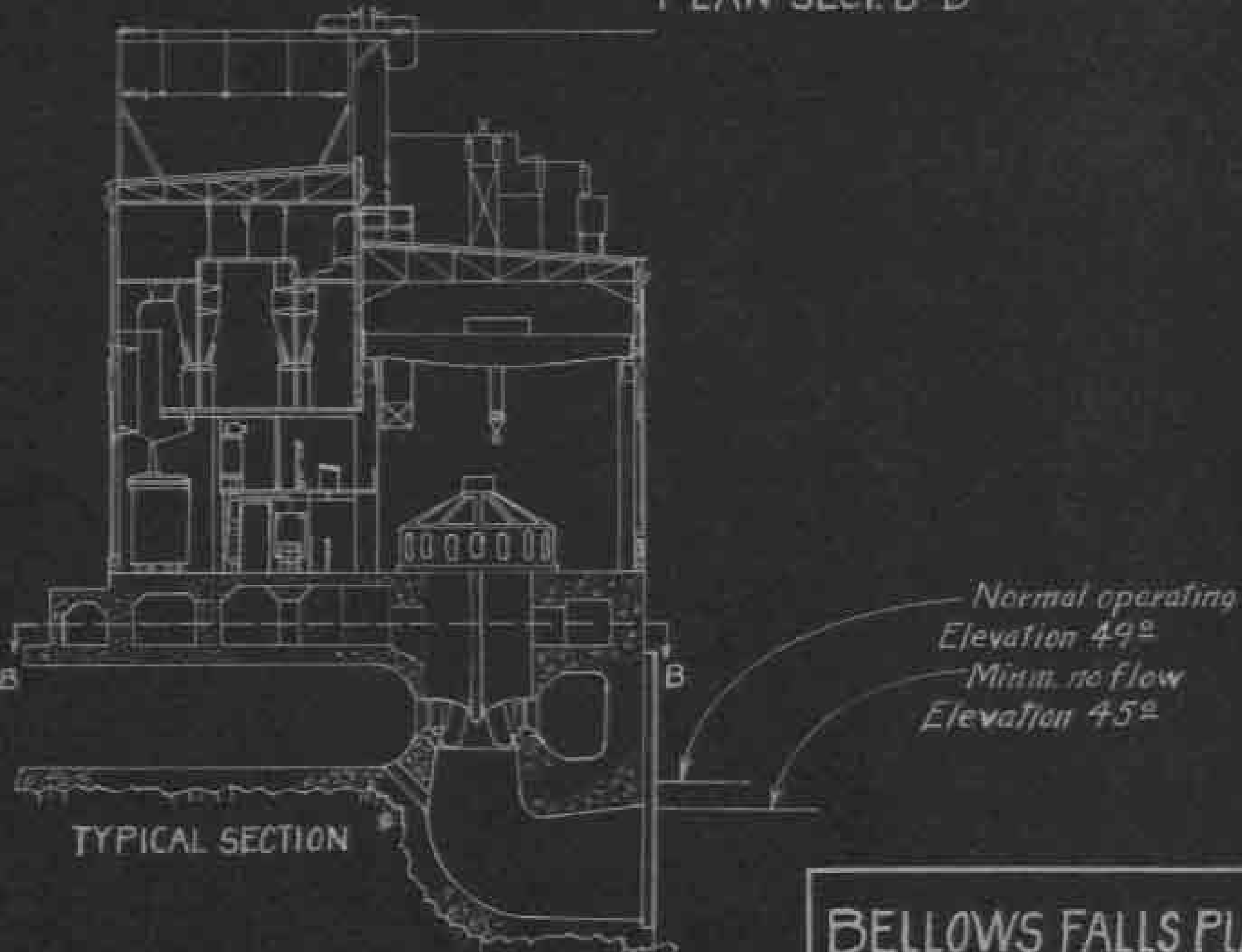
NEW ENGLAND POWER SYSTEM
HYDRO-ELECTRIC PLANT
VERNON, VERMONT
1920 EXTENSION
COMPOSITE SECTIONAL ELEVATION
LOOKING EAST
SCALE


PLAN-AA
No. 2 Line - Worcester
No. 1 Line - Worcester
Present Keene Line
Future Keene Line
SECTIONAL ELEVATION-GG-
-Main Bus Taps — Present Bus Tie - Future Keene Line.-
Main Bus
Aux. Bus
LONGITUDINAL ELEVATION-CC-
SECTIONAL ELEVATION-FF-
Auxiliary Bus Taps — Present Keene Line-
From Power Station Auxiliary Bus
Present Keene Line
REFERENCE DRAWINGS
NEW ENGLAND CO. - POWER SYSTEM
VERNON EXTENSION OF 1919
OUTDOOR SWITCHING STATION
ARRANGEMENT OF ELECTRICAL EQUIPMENT
POWER CONSTRUCTION CO.
H-599-


H-600-
MATERIAL LIST
DESCRIPTION
Main Bus
Auxiliary Bus
SECTIONAL PLAN-BB-
LONGITUDINAL ELEVATION-DD-
SECTIONAL ELEVATION-EE-
Top of Foundations
REFERENCE DRAWINGS
NEW ENGLAND CO. POWER SYSTEM
VERNON EXTENSION OF 1919
OUTDOOR SWITCHING STATION
ARRANGEMENT OF ELECTRICAL EQUIPMENT
POWER CONSTRUCTION CO.
H-600-



PLAN SECT. B-B



TYPICAL SECTION

BELLOWS FALLS PLANT
POWER HOUSE SECTIONS

SCALE 1" = 30' DATE Nov. 18, 1918

POWER CONSTRUCTION CO., ENGRS.
WORCE[illegible] MASS.

E-731-1